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VOLUME III

TECHNICAL AND ECONOMIC FEASIBILITY ANALYSIS

MANDATORY VEHICLE EMISSION INSPECTION
AND MAINTENANCE
PART A - FEASIBILITY STUDY
FINAL REPORT

Prepared Under Contract

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Approved by

R. L. Gibney, Vice President
Environmental Systems

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NORTHROP CORPORATION
Electro-Mechanical Division
500 East Orangethorpe Avenue
Anaheim, California 92801

in association with

OLSON LABORATORIES, INC.

FOREWORD

The Second Annual Report of the Air Resources Board, titled "Air Pollution Control in California," published in January 1970, documents the activities of the Board during 1969. In addition to a review of its many accomplishments, it was stressed that many problems remained to be solved. One of these was to determine the effects of various maintenance procedures on exhaust emissions and to develop a practical vehicle inspection program. In accordance with a legislative directive (AB76), the Air Resources Board issued a Request for Proposal on July 3, 1970, to conduct a Vehicle Emission Inspection and Maintenance Study that would determine the feasibility of such a program. Northrop Corporation, Electro-Mechanical Division, was selected to perform this study; Standard Agreement number ARB-1522 was consummated on November 30, 1970. Part A of the study addressed the overall feasibility and public acceptability of a program of mandatory vehicle emission inspection and maintenance. Part B of the total study which will be completed during November 1971 will obtain data on the reductions of automotive emissions that can be achieved through vehicle inspection and maintenance.

Part A of the study has been completed, documented, and is presented herewith in accordance with the requirements set forth by the Standard Agreement. This final report is presented in four volumes. Volume I is the Summary which provides a synopsis of the analytical methodology employed to determine and evaluate the feasibility of a statewide inspection program. The findings and results of the analyses are summarized, and recommendations for further effort are provided. Volume II is the Recommended Vehicle Emission Inspection and Maintenance Program. Volume III is the Technical and Economic Feasibility Analyses. It describes the conduct of the study; provides the findings, results, and conclusions of the analyses; and recommends areas for further investigation. Volume IV is the appendixes which contain data references, relevant correspondence, instrumentation survey data sheets, and other substantiating documentation.

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SECTION 1
INTRODUCTION

This volume of the Vehicle Emission Inspection and Maintenance Study Final Report completely describes the conduct of the study, and provides the findings, results, and conclusions of the analyses. This information is presented in ten sections, each presented so as to easily identify the requirements of the program. This section defines the problem, describes the purpose of the study, delineates the scope of the effort, and briefly summarizes the analysis techniques and results.

Section 2, Inspection Program Requirements and Feasibility Study Approach, presents the principal elements of a mandatory vehicle emission inspection and correction program and requirements therefor. Section 3, Instrumentation and Test Equipment, identifies and evaluates all available equipment with respect to cost, reliability, maintainability, skill requirements, degree of automation required, flexibility, and obsolescence. Also discussed is the cost of developing new equipment as opposed to improving existing equipment. Section 4, Inspection Facility Requirements, presents the development of personnel, training, and facility location requirements based on the functional requirements given in Section 2.

Section 5, Effectiveness Criteria and Evaluation, presents the optimum inspection test regime considering emission reduction effectiveness. Section 6, Program Cost Analysis, describes program costs including such items as capital investments, wages and salaries, training, and vehicle owner inspection fees. Section 7, Public Opinion Survey, discusses public opinion concerning emission inspection requirements. Section 8, Program Cost-Effectiveness, integrates the effectiveness analysis of Section 5 and cost analysis of Section 6 to determine the optimum inspection test regime. Section 9, State Versus Privately Operated Stations Cost-Effectiveness Analysis, covers the benefits and shortcomings of State versus private ownership and operation. Section 10 presents the conclusions for the work described in this volume.

1.1 STATEMENT OF THE PROBLEM

Approximately 45 percent of the total California passenger vehicles (pre-1966 vintage) do not have any exhaust emission control devices or systems. Although these uncontrolled vehicles are diminishing in numbers with each calendar year, those remaining will continue to contaminate the air in far greater proportion than their number would indicate. Numerous studies have been conducted to determine the factors that influence vehicle emissions. Based on these investigations and the institution of both state and federal regulations, manufacturers are developing and producing vehicles with exhausts that are becoming increasingly "cleaner" with each newer model-year vehicle. However, two significant problems still remain to be resolved. First, there are no state-certified and approved control devices currently available for installation on the pre-1966 or uncontrolled vehicles that would significantly decrease exhaust emissions of hydrocarbons, carbon monoxide, and oxides of nitrogen. Second, as both the controlled and uncontrolled vehicles accumulate time and mileage, a predictable deterioration of vehicle emissions occurs.

Studies conducted by governmental agencies and the automotive industry have shown that corrective maintenance and adjustments can beneficially affect rising emission levels. Many feel that a vehicle emission inspection program, that would identify those vehicles requiring corrective maintenance and adjustments, could become an effective method of reducing exhaust pollutants. There are many different inspection schemes, each purported to be the best for a statewide program. The California Air Resources Board has identified four inspection and test concepts as possible candidates for implementation. These concepts cover the total spectrum of sophistication from the reasonably simple to the relatively complex. They are the Certificate of Compliance, the Idle Test, the Key Mode Test, and the Diagnostic Test.

1.2 INSPECTION AND MAINTENANCE PROGRAM OBJECTIVES

The overall objective addressed in this study is to assist the State of California in achieving improved air quality by the reduction in vehicle emissions of hydrocarbon (HC), carbon monoxide (CO), and oxides of nitrogen (NO_X). To meet this objective, the California State Legislature wishes to consider the implementation of a statewide network of inspection facilities. Before recommending such a program, the Air Resources Board requires information on the overall technical and economic feasibility, and the public acceptability and benefits of a mandatory periodic inspection and maintenance program. This report provides such information.

The recent upsurge of interest in the control, regulation, surveillance, and instrumentation of vehicle exhaust emission is well founded. The second annual report of the Secretary of HEW to Congress stated that automotive sources continue to emit more air pollutants than all stationary sources combined (reference 1). This report states that the automobile is responsible for over 90 percent of the oxides of nitrogen emitted into the nation's air. Thus, the state program objective in seeking a means of reducing HC, CO, and NO_X from the atmosphere will contribute directly to alleviating the total air pollution problem.

Although control measures have been effected in California for several years, the absolute amount of emissions by automobiles is still very high. The Air Resources Board in its annual report to the Governor (reference 2) estimated that in the South Coast Basin (Los Angeles Area) in 1970 automobiles produced over 2300 tons of hydrocarbon per day, over 11,000 tons of carbon monoxide per day, and over 900 tons of oxides of nitrogen per day. These emissions represented approximately 70 percent of the hydrocarbon and 67 percent of the oxides of nitrogen emitted from all sources in the basin.

1.3 STUDY PURPOSE

The purpose of this study, then, is to determine if the State of California should institute any of these test concepts or others in a program of mandatory vehicle emission inspection. To resolve the issue, questions similar to those listed below are answered in the study:

a. Which test concept is most desirable for statewide implementation?

b. Is the test concept technically feasible and realizable using current technology, instrumentation, and technical personnel?

c. What are the attendant costs, both to the State and the vehicle owner?

d. What degree of participation should the State and private industry have in the management, ownership, and operation of statewide facilities?

e. What is the general public's reaction to a mandatory inspection program?

f. What benefits will the State and the public realize from this program?

In brief, this study evaluates the technical feasibility of various test concepts, identifies and quantifies program costs, elicits and analyzes public opinions, describes total program benefits, and defines an implementation program.

1.4 STUDY SCOPE

The total study has been contractually divided into two parts. Part A of the study delves into the questions related to technical and economic feasibility, and also public acceptability and benefits. Part B of the study is structured to obtain empirical operational data from vehicle testing and maintenance performed in accordance with the four test concepts. The data is analyzed and used as inputs to the feasibility analyses of Part A.

This report documents the investigation conducted as Part A of the study. Each of the four test regimes is investigated in terms of technical feasibility, total program implementation costs including state and vehicle owner's costs, public acceptability and benefits. In addition, some preliminary analysis of the technical and economic aspects of a Constant Volume Sampling system is conducted in anticipation of possible future requirements.

Part B is a 12-month study involving 1320 privately owned vehicles (less than 6001 pounds) to be inspected and serviced as determined by procedures of the four test regimes. The study was separated into two operating phases: a Learning Phase involving 120 vehicles and the main-test phase involving 1200 vehicles. A Learing Phase Final Report covering the activities of the initial 120-vehicle pilot program was issued to the Air Resources Board on 22 January 1971.

Approximately half of the scheduled main phase testing has been completed, and the data applicable and relevant to the feasibility analyses (Part A) have been assimilated. During the remainder of this study effort, the remaining vehicles comprising the 1200-vehicle sample will be tested and serviced. In addition, one-half of the 1200 vehicles tested and serviced will be recalled 6 months after their original test to provide data to determine degradation effects of various types of vehicles. This operational program will be concluded in November 1971. The main test program will be documented and the study results released during December 1971.

1.5 BACKGROUND

1.5.1 Effect of Automobile Emission on Air Quality

Since the early 1950s, the automobile has been identified as a factor in the deterioration of Air Quality in California. High atmospheric concentrations of carbon monoxide (CO), volatile hydrocarbons (HC), oxides of nitrogen (NO_x), and particule matter (PM) are, in large part, directly attributable to automobile exhausts.

Additional large quantities of hydrocarbons are emitted by evaporation from automobiles and from the operation of filling stations. The production of photochemical smog by the atmospheric reaction of the hydrocarbons and the nitrogen oxide, under the influence of solar irradiation, has been investigated and documented by Haagen-Smit and others (references 3 and 4).

The emission of air contaminants is a basic characteristic of the modern internal combustion engine. However, the amount of pollutants emitted per mile of operation can vary widely depending on engine design factors and on conditions of operation. Proper understanding and application of these factors can result in significant reduction of pollutant emissions by cars. Added equipment can be installed on automobile engines to further reduce the quantity of pollutants emitted.

All three approaches have been applied to the reduction of harmful exhaust emissions. To meet increasingly more stringent standards, automobile manufacturers have installed emission control devices on existing engines, revised recommended engine operating parameters, and redesigned basic engine characteristics.

1.5.1.1 Nonexhaust Emissions - Automobiles use organic lubricants and fuels which contain volatile components. In pre-1963 automobiles, these compounds were normally emitted as vapor from the crankcase vent, the fuel tank vent and from the carburetor. Abnormal sources included fuel line and fuel pump leaks, and faulty or missing crankcase caps and air cleaner housings.

During engine operation, the crankcase vent was a source of excessive hydrocarbons in engines with worn or defective compression rings or cylinders which allowed "blowby" of significant quantities of unburned air-fuel mixtures. In many cases over 25 percent of the total HC emissions from a car could be attributed to vented blowby gases.

Evaporative emissions can amount to over 15 percent of the total. These losses result from evaporation of fuel from the fuel tank and carburetor vents.

1.5.1.2 Exhaust Emissions - Automobile exhaust gases include not only hydrocarbons but carbon monoxide and oxides of nitrogen. Approximately 60 percent of the hydrocarbon emission are contained in the exhaust gases. This results from lack of combustion of fuel vapors in the "quench zone" near cylinder walls and in the space between cylinder and piston above the first piston ring. Poor carburetion and incomplete mixing of air and fuel can aggravate this normal condition.

Nitrogen oxide is produced in the normal combustion process. High combustion temperatures and lean air-fuel mixtures (to the point of stoichiometry) increase the concentrations of NO in the exhaust gases. NO converts to NO_2 and other oxides of nitrogen in the atmosphere and the reactions which take place are major factors in the formation of photochemical smog.

Carbon monoxide is a product of partial combustion of the fuel and is produced in high concentrations at the high combustion temperatures encountered in the internal combustion engine. With adequate quantities of oxygen and time, most of the CO would be oxidized to CO_2 at temperatures between combustion and exhaust. However, cooling occurs at a high rate in the exhaust system allowing little opportunity for CO oxidation. Furthermore, the air-fuel ratio is usually not optimum for CO oxidation. As a result, uncontrolled engines all produce significant quantities of CO.

Modification of engine operating parameters, including idle speed, air-fuel ratio and spark timing can all affect the concentration of these pollutants in exhaust gases from normal engines. The objective of applying these modifications is to optimize the engine operation with respect to exhaust emissions. For example, by increasing idle speed and air-fuel ratio and retarding spark timing slightly from manufacturers recommendations in older engines, the emission of HC and CO often can be materially reduced. Unfortunately, these same actions tend to increase NO emissions. (When air-fuel ratios exceed stiochiometric ratios, NO formation actually decreases.) When adjustments are made which optimize engine performance with respect to emissions, the vehicle performance such as acceleration and driveability may be degraded with respect to presently acceptable standards.

1.5.2 Emission Control Techniques

1.5.2.1 Blowby and Evaporative Emissions - Early attempts at vehicle emission control included the mandatory installation of crankcase controls on all new cars sold in California beginning in 1963. (The auto manufacturers voluntarily installed these devices on California cars beginning in 1961.) The desired result of this action was to materially reduce the amount of hydrocarbons emitted through the crankcase vent. The system generally consists of a tube connecting the crankcase and the engine air intake. The tube usually contains a positive crankcase ventilation (PCV) valve which controls the flow of crankcase gases into the engine air intake. An inlet port with a filter on the crankcase prevents a vacuum buildup in the crankcase.

The following paragraphs discuss auto emission control techniques as the data to the requirements for a mandatory inspection program. A more comprehensive treatment appears in the report of the Federal Government on this subject (reference 5).

To further reduce hydrocarbon emissions, all 1970 and subsequent model cars sold in California have been equipped with devices to nearly eliminate evaporative emissions. The most common of these are activated carbon filters which absorb HC vapors from the fuel tank and carburetor. Evaluation of crankcase and evaporative emission control components consists of a simple inspection to assure they are installed properly and are functioning according to manufacturers specifications.

1.5.2.2 Exhaust Emissions - A large part of the HC emissions and all of the CO and NO produced by the automobile engine is emitted in the exhaust gases. The control of exhaust emissions has been accomplished for new automobiles by establishing standards and prescribing test procedures to evaluate these exhaust emissions. The various auto manufacturers have defined and developed the methods to meet the standards.

Exhaust emission standards for CO and HC became effective in California with the 1966 model year domestic vehicles. The standards were expressed in concentration units (percent CO and ppm HC) and were based on the weighted average of values observed with the automobile engine operating in seven different modes.

To meet these initial emission standards, the automobile manufacturers took one of two approaches. Of the major U.S. manufacturers, Chrysler incorporated engine modifications which resulted in leaner air-fuel ratios during idle and low speed cruise and during engine warmup. Spark timing was retarded to assure ignition of these leaner mixtures. The spark timing was automatically advanced during closed throttle deceleration to lengthen combustion time. The ability of the Chrysler engines to meet the 1966 and subsequent more stringent standards depends, among other things, on careful adjustment of the carburetor and ignition system and on the proper functioning of the distributor vacuum control valve.

To meet 1966 standards, the other major domestic manufacturers installed an airpump which delivered air to the hot exhaust gases as they left the engine cylinders. This resulted in more complete oxidation of CO and HC. Other adjustments on the air injection equipped cars included modified spark advance schedule, increased idling speed and an intake manifold relief valve which prevented backfiring during closed throttle deceleration. The air injection system was used on most car models for only 1 or 2 years.

Improvements in engine control systems and in engine design have subsequently resulted in better emission control and improved reliability on all domestic and foreign cars. Additional design improvements include redesigned combustion chambers and air intake systems. Better controls include tighter manufacturing and adjustment tolerances on carburetors, and optimizing spark advance control to obtain low emissions.

All of these improvements were required because exhaust emission standards were revised to lower levels in 1970. At the same time, the standards were redefined in terms of units of pollutant by weight per mile of vehicle operation. This change was incorporated to take into account the size factor (engine displacement) of the various cars.

California exhaust emission standards have existed for new cars since 1966. In this study, all domestic cars of 1965 or earlier are referred to as "uncontrolled" -- those of 1966 and later as "controlled."

Although the Federal government has specifically pre-empted the authority to set emission standards for new vehicles, a special waiver provision permits the State of California to establish and enforce more restrictive standards and procedures than the national standards. California has already established standards for NO_x beginning with the 1971 models, becoming more stringent in 1972, and still more stringent in 1974. The California standards for HC in 1972 are also more strict than existing federal standards. Table 1-1 indicates the trends in emission limits (concentration measurement) as imposed by the Federal and California regulations. Table 1-2 shows the emission control requirements using CVS mass measurement that becomes effective on 1972 vehicles. All calculations contained in this report were based upon concentration measurements.

1.5.3 Deterioration and Effects of Maintenance

The criteria and standards established for automobile exhaust emissions have been applied mainly to automobiles at the time of initial manufacture or subsequent transfer of title. Except for apprehension of flagrant smoke emitters, little effort has been expended to ensure continued performance of emission control systems. Furthermore, the test and inspection of new cars has actually been acomplished only on a relatively few individual cars of each model type. For example, present California regulations require that only 2 percent of each new car model be tested by the official certification test procedure. Certification procedures require only that the average emissions of prototype fleet pass the standards. Furthermore, individual production vehicles are not required to meet the standards. Some cars, which initially meet the standards, deteriorate in performance during their lifetime. This may be due either to wear or to deliberate maladjustment of engine performance parameters by the owners.

Table 1-1. CALIFORNIA AND FEDERAL GASOLINE-POWERED VEHICLE EMISSION STANDARDS FOR HC, CO, AND NO_x (FTP CONCENTRATION MEASUREMENT)

Pollutant	1963	1966	1968	1970	1971	1972	1974	1975*	1980*
California									
Crankcase Exhaust	0.15%	0.10%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	
HC	NR	275 ppm (3.35 gpm)	275 ppm (3.35 gpm)	2.2 gpm	2.2gpm	1.5 gpm	1.5 gpm	0.5 gpm	
CO	NR	1.5% (34 gpm)	1.5% (34 gpm)	23 gpm	23 gpm	23 gpm	23 gpm	12 gpm	
NO_x	NR	NR	NR	NR	4 gpm	3 gpm	1.3 gpm	1.0 gpm	
Evaporative HC	NR	NR	NR	6 gpt	6 gpt	6 gpt	6 gpt	6 gpt	
Federal									
Crankcase Exhaust	NR	NR	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HC	NR		275 ppm (3.35 gpm)	2.2 gpm	2.2 gpm	2.2 gpm	2.2 gpm	0.45 gpm	0.25 gpm
CO	NR		1.5% (34 gpm)	23 gpm	23 gpm	23 gpm	23 gpm	11 gpm	6.0 gpm
NO_x	NR	NR	NR	NR	NR	NR	NR	0.9 gpm	0.5 gpm
Evaporative (HC)	NR	NR	NR	NR	6 gpt	6 gpt	6 gpt	6 gpt	6 gpt
Particulates	NR	NR	NR	NR	NR	NR	NR	0.1 gpm	0.1 gpm

NOTE: ppm - parts per million
gpm - grams per mile
gpt - grams per test
NR - no regulations

( ) Shown for cross reference purposes only.

*Proposed standard as extracted from Research Project S-10, PROJECT CLEAN AIR, University of California, September 1, 1970.

Table 1-2. EMISSION CONTROL REQUIREMENTS
PASSENGER CAR AND LIGHT TRUCK (UNDER 6001 LB. G.V.W.)

Emission, Gm/Mi	1972 Calif	1972 Fed	1973 Calif	1973 Fed	1974 Calif	1974 Fed	1975 Calif	1975 Fed	1976 Nation
Test Procedure	CVS (Mass Measurement)								
Hydrocarbons	3.2	3.4	3.2	3.4	3.2	3.4	0.46		0.46
Carbon Monoxide	39		39		39		4.7		4.7
Nitrogen Oxides	3.2**	NR	3.0		1.3	3.0	1.3	3.0	0.4
Evap. (Gm/Test)*	2		2		2		2		2

NR - No Requirement
*Proposed
**Two hot cycles FTP test

Studies already completed show that acceptable emission performance for most cars can be achieved and sustained by proper maintenance and repair (references 5, 6, 7). The maintenance work must be emission reduction oriented to achieve the desired results, indicating a necessity for established standards of training and experience of the mechanic.

One of the earlier investigations was conducted by the California Motor Vehicle Pollution Control Board (now the Air Resources Board) in conjunction with Scott Research Laboratories, San Bernardino. This investigation evaluated the cost-effectiveness of various tuneup approaches in reducing exhaust emissions of uncontrolled vehicles (reference 8).

The experiment divided the sample of vehicles into four groups. After general tuneup was performed by representative garages and service stations on the first group of vehicles, the average changes in emissions were insignificant. The second group of cars was given tuneups by new car dealers using instructions provided by the Automobile Manufacturers' Association. Results obtained were similar to that of the first group. For the third group, Scott Laboratory used a chassis dynamometer and oscilloscope to perform detailed engine diagnostic tests. Indicated deficiencies were corrected, idle air-fuel ratio was adjusted on the lean side, and idle rpm adjusted to 75 rpm above manufacturer's specification. As a result, HC decreased by an average 28.9 percent while CO decreased by 13.4 percent. For those vehicles that received carburetor overhaul by Scott, the average decrease in HC was 44.8 percent while CO decreased by 25.6 percent. For the fourth group, Scott Laboratory performed a "package" tuneup during which spark plugs and distributor points were arbitrarily replaced annually, high-tension wires and air cleaner elements were replaced every 2 years, idle air-fuel ratio adjusted on the lean side, idle speed set 50 rpm faster than manufacturer's specification, and spark timing retarded 5 degrees. Average reductions for this group were 27 percent of HC and 21 percent of CO.

Data on cost of inspection and maintenance were collected. These generally indicate that effective emission control procedures are more costly than ineffective methods. The study was significant in that it showed that only those tuneups conceived to reduce exhaust emissions were really effective in this regard.

In another study that investigated exhaust emissions from controlled vehicles, it was demonstrated that high emissions can be lowered, in most cases, with engine adjustments and tuneups performed by a qualified commercial garage (reference 9). A study dealing with 1966 model General Motors cars equipped with AIR (Air Injection Reactor) control systems showed that the need for proper maintenance becomes very important (reference 10). For this study, the vehicles were divided into four mileage groups: 4,000, 8,000, 18,000, and 21,000 miles. Within each group the average HC and CO emissions were reduced after restoring the engine to proper operating conditions with normal tuneup procedures and periodic replacement of air cleaner elements.

The results of all studies examined may be summarized in two points. First, the incorporation of emission controls on cars does not assure continued low emissions. The control systems tend to deteriorate in their performance. Second, with proper maintenance and adjustments, vehicles will operate with lower emission levels. The issue, then, is to determine the best method of identifying these vehicles that require the necessary adjustments and maintenance and to accomplish the necessary repairs or adjustments. The following section describes various inspection and test regimes considered in this study for this purpose.

SECTION 2
INSPECTION PROGRAM REQUIREMENTS AND FEASIBILITY STUDY APPROACH

This section describes the requirements analysis conducted to establish a baseline from which further analysis may proceed. Current trends in state and federal regulations are evaluated in anticipation of future requirements. That is, as the implemented program progresses in years, those future emission requirements imposed on the newer model-year vehicles could possibly become part of the statewide surveillance program. Past and current efforts to reduce and control emissions are described, and the effects of vehicle maintenance as identified in past studies are evaluated. This provides valuable background information which is used to formulate the investigation and to evaluate interim study results.

Candidate emission inspection and test regimes are described. A functional analysis of the inspection facilities identifies inspection, test, administrative, and support activities necessary to operate a facility. Similarly, a top-level functional analysis of program management and administration activities is performed. The results of the functional analyses are used to define operational requirements and also to identify total program implementation cost elements discussed later in the report.

2.1 INSPECTION TEST REGIMES

In this study, various short test cycles were evaluated with reference to the hot-start version of the standard seven-mode test. This hot-start test is a modification of the seven-mode, seven-cycle test presently specified by the California and Federal agencies. The seven-cycle, seven-mode certification test is designed to determine HC, CO, and NO_x concentrations as emitted by a vehicle on an average metropolitan trip of 17 minutes duration. A chassis dynamometer is used to simulate typical road-load conditions. The total test is comprised of two parts; these are four seven-mode warmup cycles and three hot cycles. Each seven-mode test consists of two periods of accelerations, two cruises, two decelerations, and one idle period. The average concentrations for the two parts are weighted and combined to yield a composite value for each of the three concentrations.

The standard cold-start test requires that the vehicle not be operated for a period of about 12 hours immediately before testing. To ease scheduling problems and to provide a more uniform referral test, the seven-mode hot-start test is used in this program. This test is the last two complete cycles of the standard test. The vehicle is preconditioned by operating it until normal operating temperature equilibrium is attained (8 to 15 minutes), after which two cycles of seven-mode (two accelerations, two cruises, two decelerations, and one idle) are run. As in the standard test, a single value is derived for each of the three pollutants. In this study, the results of four short-form tests are being compared to results of the seven-mode hot-cycle test. These four are Certificate of Compliance, Idle, Key-Mode, and Diagnostic test regimes.

2.1.1 Certificate of Compliance Test Regime

In accordance with the requirements of Chapter 4, Part 1, Division 26 of the Health and Safety Code and the rules and regulations of the Air Resources Board, a Certificate of Compliance is issued to indicate that the identified vehicle is properly equipped with the motor vehicle pollution control device(s) required by law. The certification is required and obtained ordinarily during transfer of ownership as directed by the Vehicle Code. However, the certificate may be requested by the California Highway Patrol and issued any time proof of compliance is desired. The Certificate of Compliance inspection and servicing procedure involves the following sequence of operations. For uncontrolled vehicles, service the crankcase device, remove and replace if necessary. For controlled vehicles, visually inspect pertinent connections and perform required engine adjustments. In this program, some basic adjustments recommended by the Air Resources Board, beyond present certification requirements were added for uncontrolled vehicles.

2.1.1.1 Crankcase Devices - The following synopsis of events has been extracted from the CHP handbook (reference 11):

a. Identify and confirm that the vehicle has an approved device installed.

b. Test the device for satisfactory operation with the engine warm and at idle condition.

c. Clean, service, or replace device in case of unsatisfactory operation. Use the manufacturer's recommended instructions.

2.1.1.2 Exhaust Emission Control Systems - To continue meeting California emission standards, the necessary maintenance and adjustments must be accomplished according to manufacturer's recommendations and specifications. The control system inspection involves checking those items and adjustments of an engine which affect exhaust emissions. The procedures are:

a. Visually check all installation connections to airpump, hoses, valves, and air distribution manifolds while engine is stopped.

b. With engine at normal operating temperature, check and/or adjust ignition timing, idle mixture, and idle speed to manufacturer's specification.

2.1.1.3 Additional Procedures for Uncontrolled Vehicles - To achieve a greater emission reduction on uncontrolled vehicles, the Air Resources Board has recommended that Northrop also include the basic idle adjustments as an integral part of the Certificate of Compliance procedures. The following recommendations were implemented in the vehicle testing portion of the study, Part B.

a. Measure idle rpm and adjust, if necessary, to a speed no slower than manufacturer's specifications.

b. Measure the ignition timing and point dwell; adjust if necessary to manufacturer's specifications. For certification purposes, adjustment is required only when the timing is advanced more than 3 degrees from manufacturer's recommended setting.

c. Measure the air-fuel ratio and adjust, if necessary, to 12.5 to 13.5 on uncontrolled vehicles.

2.1.2 Idle Inspection Test Regime

As previously described, the seven-mode test involves operating the vehicle under simulated load conditions in various driving phases that included two accelerations, two cruises, two decelerations, and an idle mode. A mathematical approach, based on decision analysis, has been used to determine whether or not any of the modes could identify the high emitters of HC and CO (reference 12). The analysis of data obtained and used in previous studies conducted by the Auto Club, the Air Resources Board, and the State of New Jersey, revealed that the measurement at idle is capable of identifying high emitters of CO or HC.

In this inspection and test regime, the tested vehicle is operated until proper engine temperature is achieved. While the vehicle is operating at idle, a sample of the exhaust is analyzed for HC and CO concentration in the gas analyzers and the results are recorded. If the vehicle does not pass the established emission limits, the vehicle then will be required to receive corrective action.

2.1.3 Key Mode Inspection Test Regime

One type of engine diagnostic technique based on experimentally derived data indicates that unnecessarily high emissions are caused by specific maladjustments or malfunctions. When these deficiencies are corrected, the emission characteristics of the vehicle engine are as good as can be obtained by the repair facility. The technique was developed by determining the minimum number and variety of operating modes required to expose these deficiencies and defects.

Those operating modes that most reliably exposed these engine faults were labeled "Key" modes (reference 13). These modes have been named high cruise, low cruise, and idle. For each of these modes, different failure limits are established for HC and CO concentrations. By referring to a logic diagram termed a "truth" chart, corresponding probable engine malfunctions and adjustments are denoted as an aid to the repair technician. Test vehicles must be operated on a chassis dynamometer during the key mode test and inspection procedures. A sample probe is inserted in the exhaust tailpipe, the gas is drawn off, and analysis of CO and HC made by the appropriate gas analyzers.

2.1.4 Diagnostic Inspection Test Regime

The most sophisticated inspection and test concept involves the utilization of a diagnostician, chassis dynamometer, oscilloscope, and other engine analysis equipments. A skilled and trained diagnostician, following a set of well-developed procedures, can accurately analyze faulty engine operation and also specify the necessary service (reference 14). The chassis dynamometer is used to simulate driving and road conditions designed to represent the steady-state modes of operation of idle, full-throttle at 60 mph, cruise at 50 mph, and a transient deceleration mode. During each of the operating modes, the exhaust is analyzed for concentrations of HC. CO is measured in all modes except deceleration. Vehicles failing the established limits are diagnosed by the diagnostician using the oscilloscope console. The scope patterns for common engine discrepancies are documented and serve as a diagnostic aid.

2.1.5 Other Test Regimes

2.1.5.1 ACID Cycle - New Jersey has developed the ACID short test cycle (reference 15). The test consists of the following modes: acceleration, cruise, deceleration, and idle. A dynamometer is required to impose a duty cycle (simulated road and acceleration load) at the vehicle wheels. The road load varies as the cube of simulated road speed, with a rating of 3.5 horsepower at 30 mph. The acceleration load is set at 3000 pounds and is simulated by an inertia wheel.

The New Jersey ACID cycle consists of, sequentially:

a. Constant acceleration from zero to 30 mph in a period of 14 seconds.
b. Cruise at 30 mph for 16 seconds.
c. Constant deceleration from 30 mph to 0 mph in 14 seconds.
d. 0 mph (idle) for 16 seconds.

2.1.5.2 General Motors EXIT Cycle - General Motors has developed a rapid test which was based upon a study of the application of the New Jersey ACID cycle to assembly line conditions. The final cycle developed is performed as follows:

a. The driver receives the car at the end of the assembly line and drives it forward onto a set of powered dynamometer rolls.

b. The driver then inserts a punched card into a card reader which inputs the computer vehicle information such as engine size, transmission type, and other options. The computer then establishes the specifications which must be met by that vehicle.

c. The driver accelerates the vehicle to approximately 35 mph at which time the computer takes over and maintains driving speed at exactly 35 mph.

2.2 INSPECTION STATION FUNCTIONAL REQUIREMENTS

The above paragraphs have briefly described the basic requirements of various candidate inspection and test regimes. In the following paragraphs, a functional analysis is conducted to identify and describe the inspection and test facility functions. Administrative and support functions necessary to complement the major inspection functions are identified. Functions normally required to start an operation such as selection and acquisition of personnel, equipment, and site are also included. Functional flow block diagrams facilitate the analysis. The results of the functional analysis are used to identify personnel, equipments, and facility requirements.

2.2.1 Inspection Program Functional Requirements

Figure 2-1 is the Inspection Station Functional Flow depicting the test repair loop. The diagram shows the vehicle receiving functions, the emission testing and data collection functions, the owner consultation functions, and the repair-certification functions. For information purposes, those functions performed by the vehicle owner are also shown to illustrate and define interface requirements.

Each of the functional blocks should generate either facility or operational requirements. Facility requirements are those related to vehicle processing such as access roadways, the building, and personnel and instrumentation accommodations. The

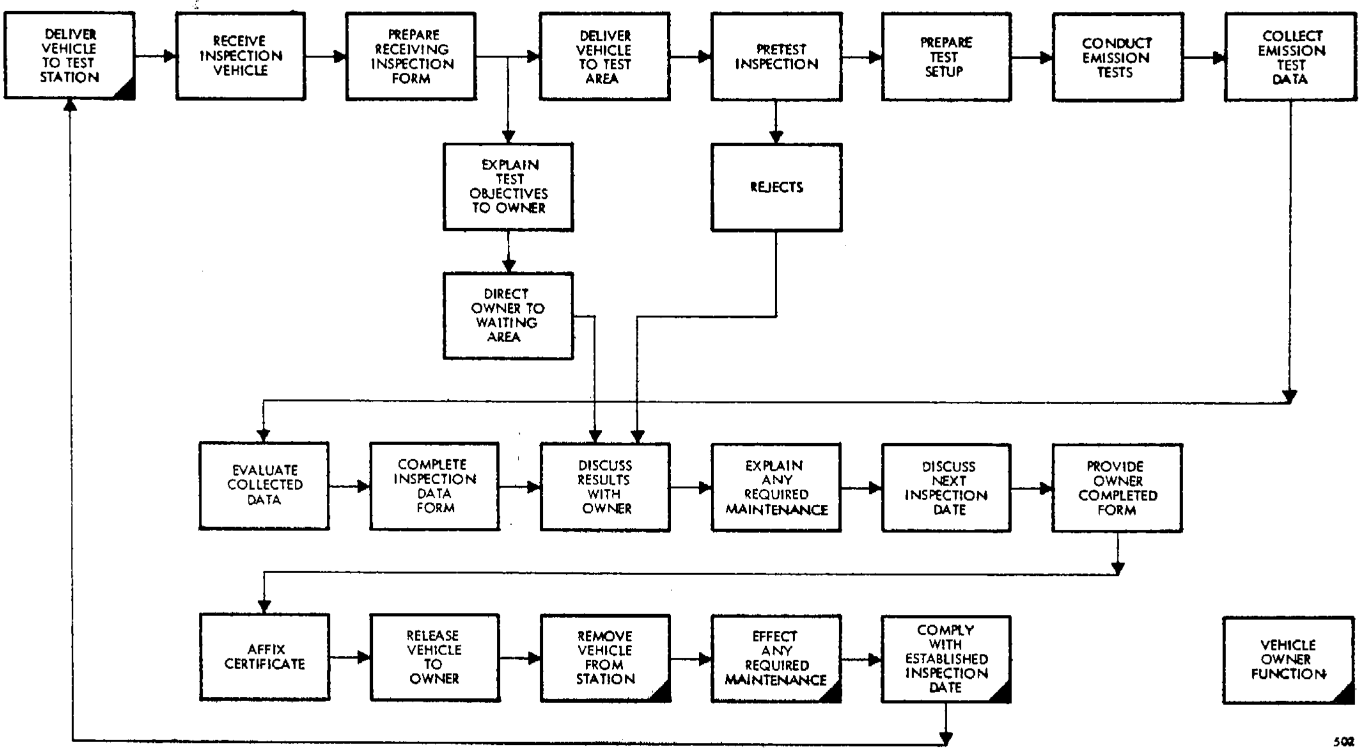


Figure 2-1. INSPECTION STATION FUNCTIONAL FLOW TEST/REPAIR LOOP

operational requirements are those essentials necessary to accomplish specific test and inspection functions. In most cases, operational considerations are satisfied by personnel, instrumentation, or software procedures and documentations. Detailed functional analysis by test regimes are included in Section 4.

2.2.2 Administrative and Support Functions

In addition to the major functions of inspection and test, each facility must satisfy the requirements for administrative and support functions. Figure 2-2 shows these administrative functions. Paramount importance to assure efficient operation is the time and effort devoted to maintaining the proper operation of the inspection equipments. Periodic preventive maintenance, calibrations, and normal upkeep must be scheduled and conducted in accordance with manufacturer's recommendations to assure satisfactory operation and minimum downtime.

2.2.3 Facility Ownership and Operation Functions

Facility ownership involves those functions related to site selection and acquisition, facility plans and bids selection, facility construction and acceptance, and equipment acquisition and installation. In addition, personnel selection and training functions must be considered. Figure 2-3 illustrates the facility management, ownership, and operation functions required to support the inspection program. Some functions would not be required where existing facilities are to be used for this program. However, these facilities would require some modifications to satisfy equipment, personnel, and space requirements specific to the emission test program selected.

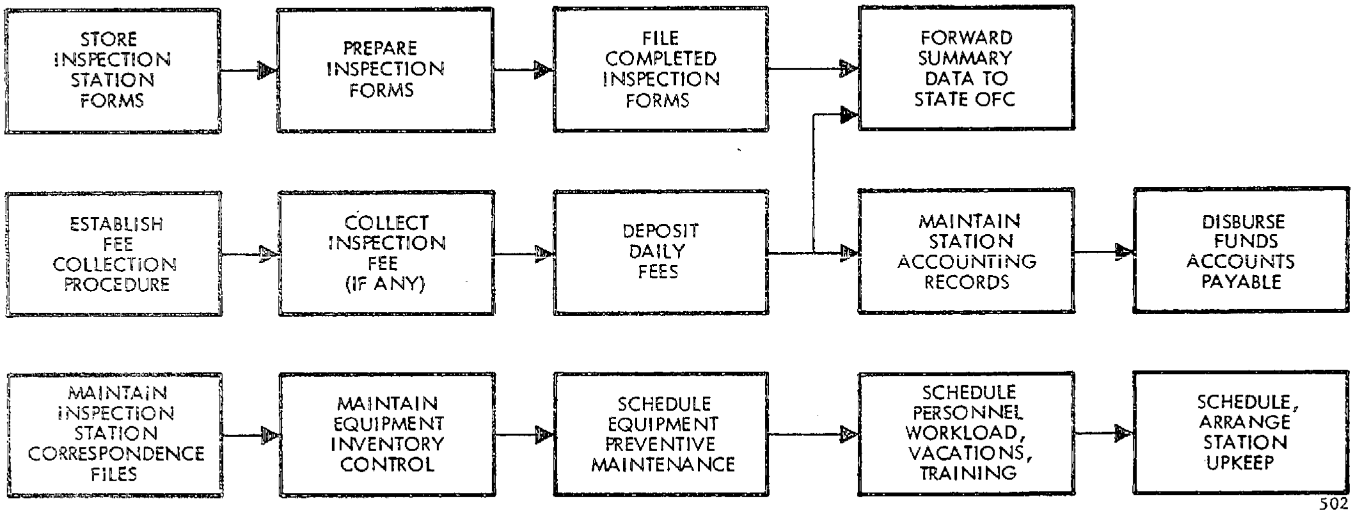


Figure 2-2. INSPECTION STATION FUNCTIONAL FLOW ADMINISTRATIVE FUNCTIONS

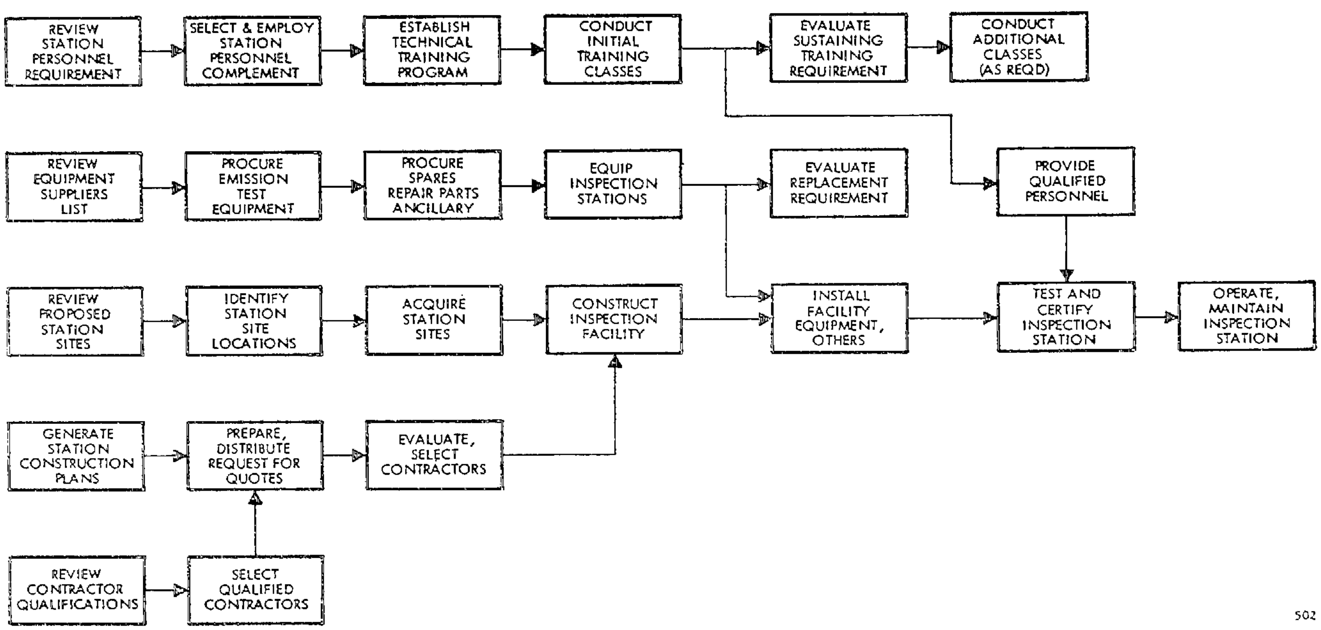


Figure 2-3. FACILITY MANAGEMENT FUNCTIONS OWNERSHIP AND OPERATION

2.2.4 Program Administration and Management Functions

To analyze the feasibility of implementing a statewide network of inspection facilities, the investigation must consider not only facility ownership and operation, but also total program administration and management. Program management of a statewide inspection system will include scheduling of vehicles, maintenance of records, establishment and review of emission limits, evaluation of current and future equipment needs, and provision for future analysis and development. If privately operated, licensed facilities are involved; program administration would include establishing qualification criteria, evaluating candidates, certifying and licensing of qualified parties. Functions required in a licensing program are outlined in Figure 2-4.

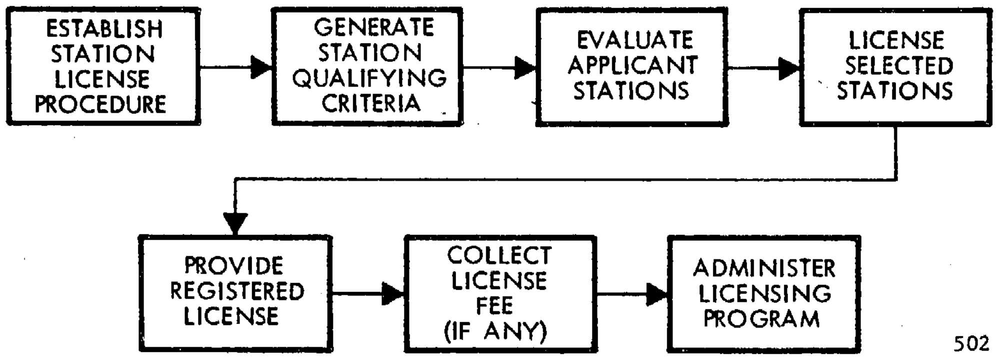


Figure 2-4. STATE PROGRAM MANAGEMENT FUNCTIONS LICENSING FINANCING AND CERTIFYING

To assure uniform performance of vehicle inspection, the program management must generate the required test specifications and procedures and conduct the necessary orientation and training sessions for test and maintenance personnel. Information from the Phase B program can be used to generate test procedures and the training program. Classes will be conducted at the outset of the program and throughout program life to accommodate changing personnel, additional facilities, and advancing technology.

The program manager's office must issue approved test procedures to all participating facilities, continually review the test results, and upgrade and refine the procedures as required, to assure uniform and repeatable inspection results, and to meet new standards established by the Air Resources Board.

2.2.5 Vehicle Inspection Scheduling Functions

The latest vehicle registration data will be used to generate the vehicle inspection schedule. Previous studies and the operational data derived as Part B of this study will be analyzed to determine a preferred inspection interval. The cost and economic analysis conducted and discussed later in this report is another determining factor to be considered in finalizing the testing cycle. An Inspection Notification Form would be distributed to the identified vehicle owners. For the initial testing it will be desirable to prepare an indoctrination pamphlet to be included with the notification form. Figure 2-5 illustrates the program management functions involved during vehicle scheduling.

Inspection-completion summaries will be prepared by inspection facilities and forwarded to the program office. At the program manager's office, certification will be confirmed, delinquent vehicles will be identified, and a delinquency list generated and maintained. A delinquency form will be distributed to the registered vehicle owner. If a delinquent penalty is imposed, the form or accompanying

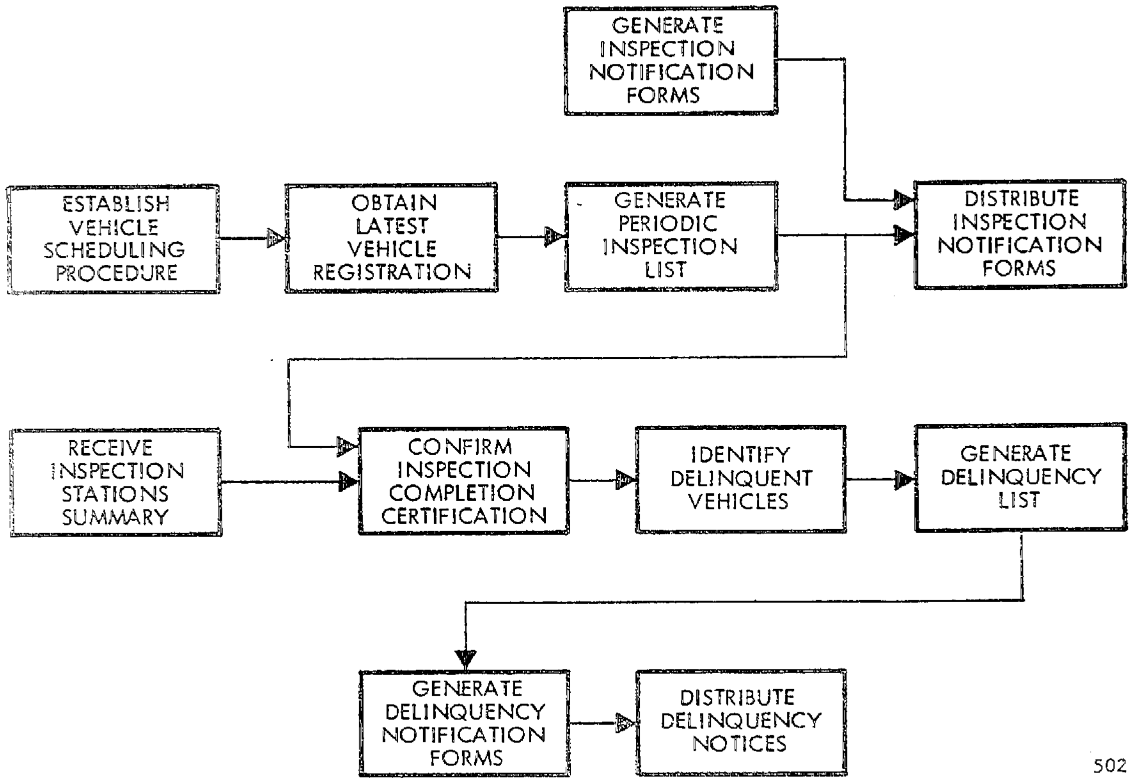


Figure 2-5. STATE PROGRAM MANAGEMENT FUNCTIONS VEHICLE SCHEDULING

information will contain the necessary procedural instructions. The instruction schedule must be continually updated to reflect current vehicle registrations and certifications.

2.2.6 <u>Establishing and Reviewing the Emission Limits</u> - Part B of this Vehicle Emission Inspection study will obtain empirical data that will be used to establish emission limits for each of the four candidate test regimes. The limits are established to accept or reject a fixed percentage of all tested vehicles within a specific test regime. During the course of the statewide implementation, continual evaluation of test results will be necessary to assure that desired coverage is being achieved. Any required changes will be reflected in the test procedures.

2.2.7 <u>Evaluating Current and Future Equipment Needs</u>

As an integral portion of the feasibility study, a comprehensive survey of existing equipments related to vehicle emission and maintenance has been conducted. The results of this evaluation, as fully described in Section 3 of this report, will identify the complement of equipment for each of the four test regimes. The program office should continually maintain cognizance of the current status of test equipment technology to assure that equipment used at the inspection facilities is current and satisfies changing test requirements. As future emission requirements become more stringent, and sampling methods are changed, the testing requirement may become correspondingly more precise. These needs should be anticipated by the program office.

2.2.8 Public Relations

The indoctrination and training of inspection personnel should be augmented with a general familiarization program for the total population. Public information generated for communication media should be carefully prepared to fully explain the program objectives and operations. The results of the public opinion survey discussed in Section 7 should be helpful in developing such information for release to the general public.

2.2.9 Program Financing

The projected cost for the various vehicle inspection and maintenance programs is discussed in Section 6. The implementation of any of the proposed programs will generate substantial requirements for capital and operating expenses. The program management must recommend and execute the initial finance plan as enacted by the legislature. The program management office, through the assistance of the applicable finance and legal agencies, would establish the requirements for total implementation of fiscal policies and budgeting. Where it is deemed necessary to institute inspection fees to support the program, the required procedures and mechanics of collection, documentation, and disbursements should be formalized before program start.

2.3 STUDY APPROACH

The Vehicle Emission Study Program specified by the Air Resources Board in Contract number ARB 1522, dated 1 December 1970, is divided into two parts. Study Part A objective is to determine the technical/economic feasibility and the public support associated with a mandatory program for emission testing and related corrective maintenance of motor vehicles in the State of California.

Study Part B objective is to determine the respective cost and benefit of various test regimes in reducing pollutants emitted to the air when performed in conjunction with corrective maintenance. This is to be accomplished through operational data collection in a pilot program utilizing test vehicles selected randomly from a representative sample of privately owned, gasoline-powered motor vehicles with maximum gross weights (as manufactured) under 6,001 pounds.

The objectives of the two study parts, in ranging from the analytical feasibility determination of Part A to the practical test and statistical data profile of Part B, establish the literal scope of the study effort. Northrop's technical approach was to integrate these objectives and their products into a logical study conclusion which provides a recommended inspection test and corrective maintenance system, optimized with respect to (1) owner and public costs, and (2) air-pollutant reduction effectiveness. This approach is considered essential to the overall purpose of the study, which is to establish not only whether mandatory inspection and corrective maintenance of motor vehicles, as a concept, is feasible (considering the range of technical, economic, psychological, and sociological factors), but what is the most feasible way to transform that air-pollutant control concept into an operational reality. This approach provides the Air Resources Board with a fully substantiated position regarding mandatory inspection and maintenance feasibility. Along with this goes an inspection and maintenance system ready for operational development and deployment.

To implement this approach, a close integration was required in the data flow from Part B, the test and statistical data recording phase, to Part A, the feasibility study phase. Figure 2-6 illustrates the flow of these two study parts and the interfacing of the respective activities to provide this flow.

The subsequent discussion further identifies specific elements of Study Part A and Study Part B; also described is the general systems management approach to integrating the two parts for maximum reliability of study results and for the desired optimization of an implementable inspection and maintenance solution. Task definitions and analysis goals have been developed. A single source of project management has been established to simplify interproject and Air Resources Board coordination in achieving the overall study objectives.

2.3.1 Scope of the Vehicle Emission Inspection and Maintenance Study

The overall intent of the defined study was to first determine the feasibility of a mandatory vehicle inspection program as a control concept and, if this concept proved feasible, to then determine the most satisfactory method of implementing the program in terms of cost and effectiveness. Study Part B is a source of laboratory data input to these determinations.

Within the context of this overall study approach, six specific points of analysis can be identified:

a. Implementation Cost and Appropriation
b. Technological Feasibility
c. Inspection Methodology
d. Maintenance Procedures
e. Program Benefits
f. State Versus Private Ownership.

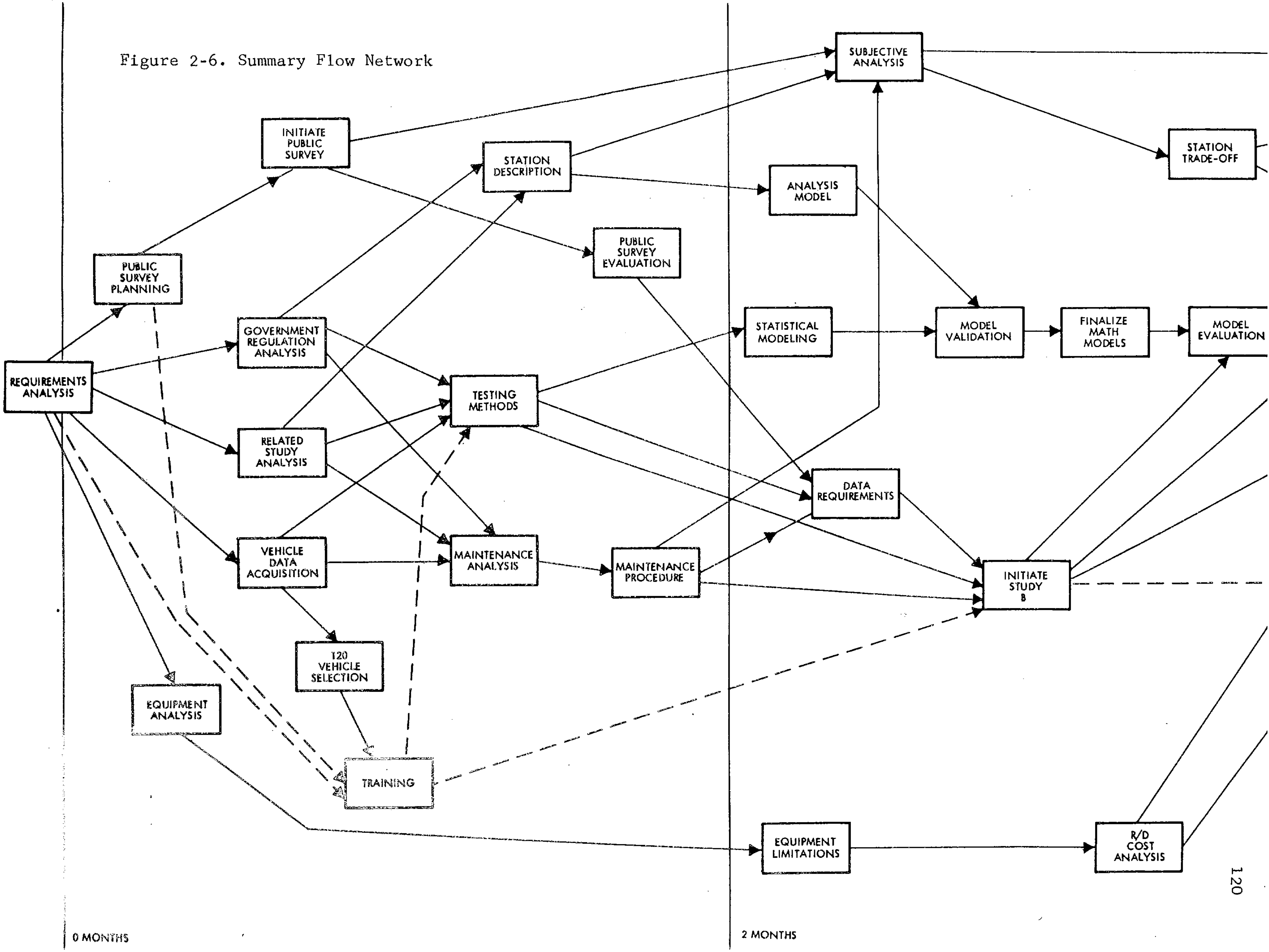
These six points logically follow as answers to such questions as:

- What will it cost and who should pay?
- Can it be done?
- How should it be done?
- What is gained for the money spent?
- What part should the State pay?
- What part should the public pay?

The study thus can be viewed as consisting of three distinct efforts: (1) data collection, (2) feasibility analyses, and (3) implementation development. Data collection encompasses all the inputs from Study Part B as well as surveys of public opinions and historical records. Feasibility is a function of technical capability, public acceptance, economic impact, and pollution reductions realizable. Satisfactory implementation is related to specific State or vehicle owner fees, continued public support, and successful station operation.

2.3.1.1 Feasibility Study - This portion of the Part A analysis was structured into two basic categories -- those elements which can be quantitatively analyzed and those which cannot. The former was identified for treatment by the computer analysis models. Subjective elements of the study were then analyzed with regard to results from the public opinion survey, experience from related studies and programs, statistical findings developed from Study Part B, and specific results

Figure 2-6. Summary Flow Network



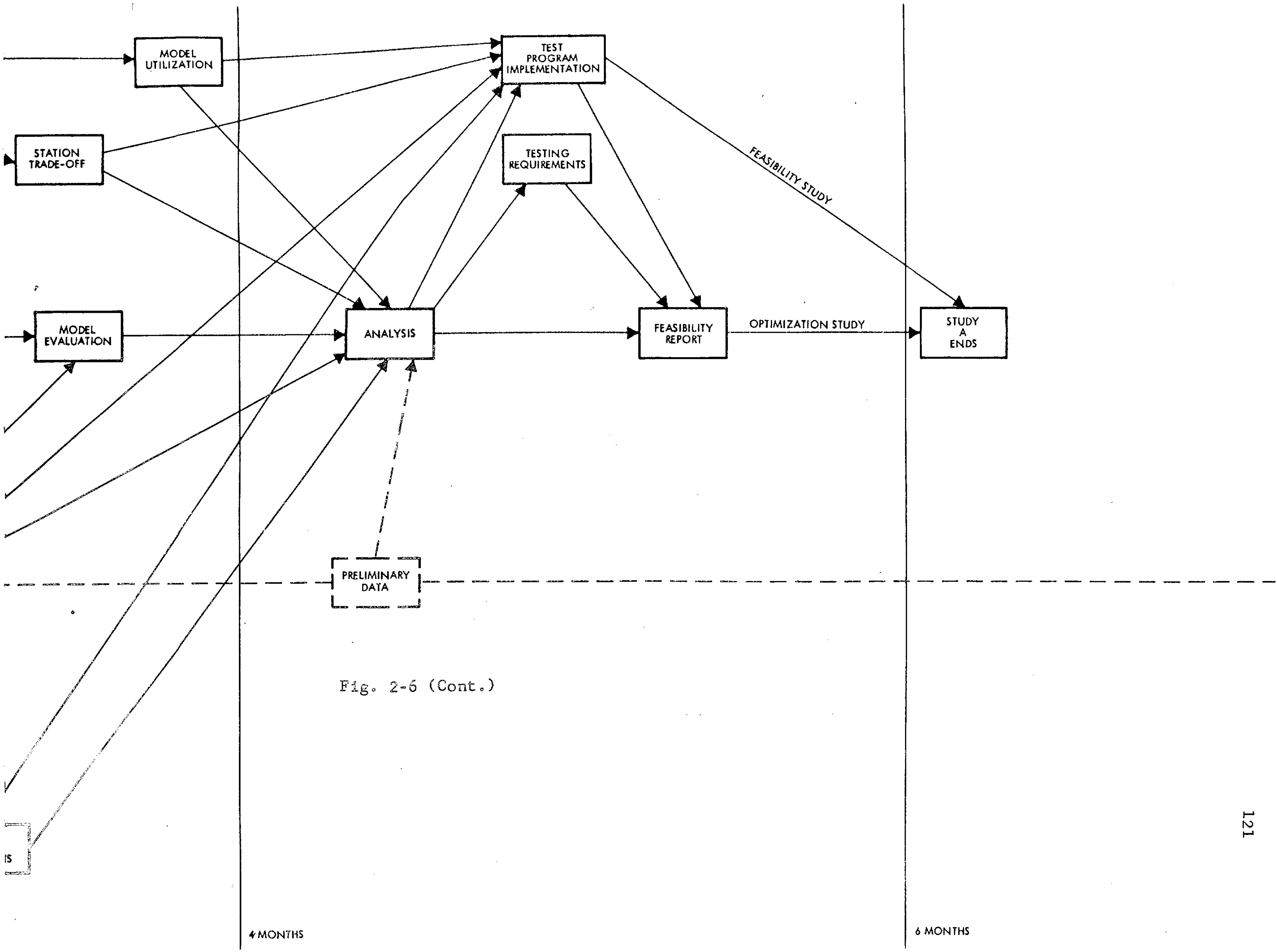

MODEL UTILIZATION
STATION TRADE-OFF
MODEL EVALUATION
TEST PROGRAM IMPLEMENTATION
TESTING REQUIREMENTS
ANALYSIS
FEASIBILITY REPORT
FEASIBILITY STUDY
OPTIMIZATION STUDY
STUDY A ENDS
PRELIMINARY DATA
IS
4 MONTHS
6 MONTHS

Fig. 2-6 (Cont.)

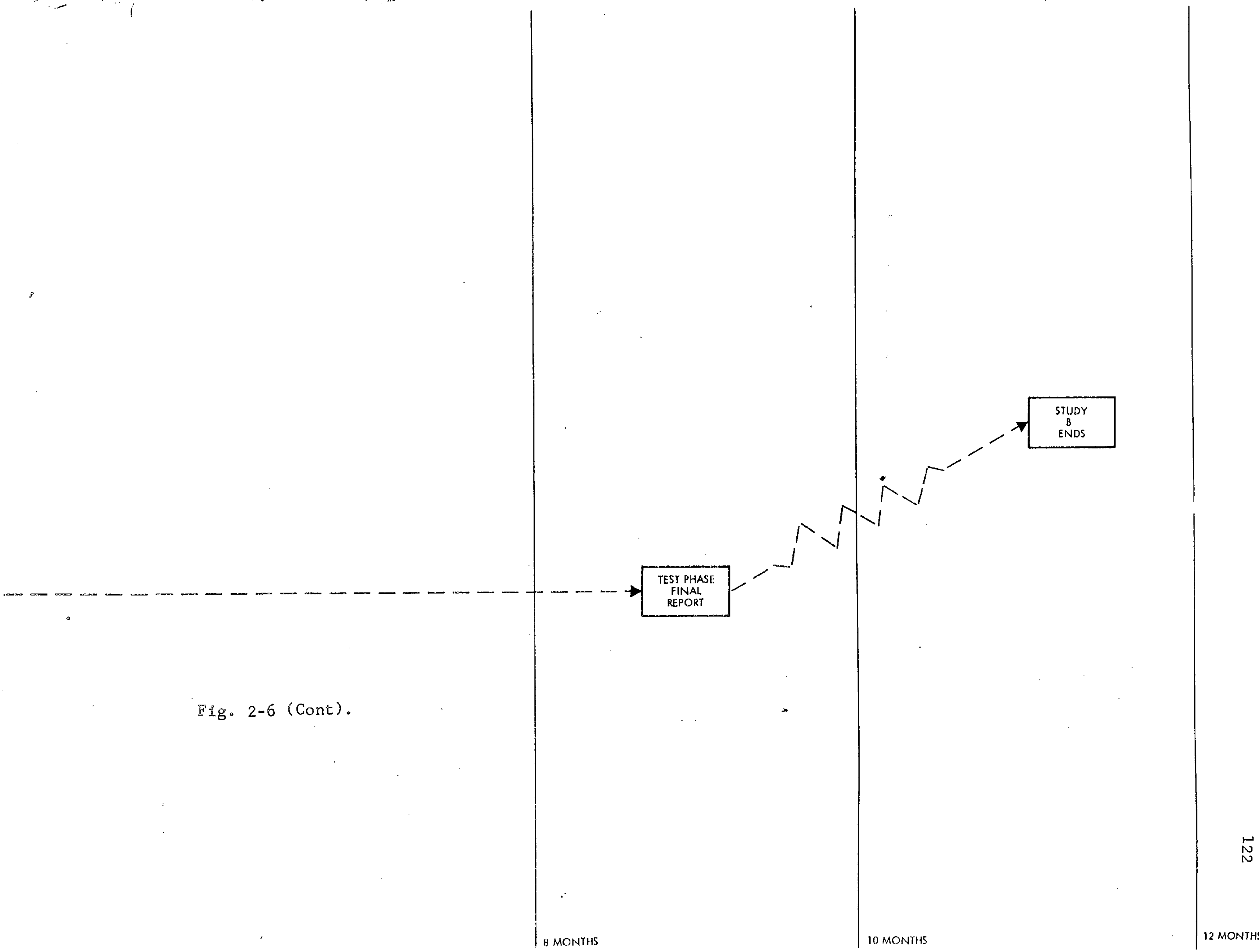

TEST PHASE
FINAL
REPORT
STUDY
B
ENDS
8 MONTHS
10 MONTHS
12 MONTHS

Fig. 2-6 (Cont).

developed by means of computer analysis models. Study Part B specifically supports this feasibility analysis by providing as much practical experience information and test data as required in a useable form to reduce subjectivity to a minimum.

2.3.1.2 Optimum System Implementation Analysis - Although this facet of the analysis also requires some subjective evaluations, it can be treated generally as a quantitative optimization study -- the tradeoff between maximized emission reductions and minimized cost. Here such factors as public support and acceptable fees are objectively evaluated based on inputs from the public opinion survey and operational data developed in Part B.

The analysis model is the primary supporting factor of this portion of the study. In essence, the subjective factors such as acceptable fees and wait times become constraints on the model. The model determines the most cost-effective implementation within scope of the constraints imposed; cost being developed from station operation less State financial benefits, and effectiveness being based upon total emission reductions.

Essentially, the feasibility analysis and the implementation study are performed within the requirements of Study A and the two elements have a considerable functional interplay. Study B is then viewed as a functional entity whose implementation logic will flow from requirements established in Study A, and whose results to date support the analyses presented in this report. To facilitate the investigation, the study was sectionalized into distinct but interrelated analytical areas. These task areas and relationships are shown in Table 2-1.

Table 2-1. ANALYTICAL TASKS RELATIONSHIPS

Task	Description
Requirements Analysis	Identifies and defines the present and future requirements of statewide inspection facilities.
Functional Analysis	Identifies requirements in terms of specific functions to be performed at the inspection facilities and at the program management office.
Operational Analysis	Analyzes the functions of the inspection facility and determines methods of satisfying each function in terms of technical personnel, instrumentation, procedures, facilities accommodations and space allocations.
Instrumentation and Systems Analyses	Surveys, analyzes, and ranks available equipments and systems that may be used within statewide inspection facilities; also identifies areas of deficiencies.

Table 2-1. ANALYTICAL TASKS RELATIONSHIPS (Continued)

Task	Description
Technical Effectiveness Analyses	Measures and projects the effectiveness of each test regime in reducing vehicle exhaust emissions in terms of hydrocarbons, carbon monoxide, and oxides of nitrogen.
Cost Analysis	Identifies and quantifies resources and expenditures necessary to implement each of the four test regimes on a statewide basis for a 20-year life cycle duration. Considers both state and private industry participation. Identifies citizens costs.
Public Acceptability Analysis	Develops a questionnaire based on program objectives and preliminary implementation and cost analysis. Analyzes public opinion survey results.
Cost Effectiveness Analysis	Combines the results of the feasibility and acceptability analyses to determine the relative merits of each test regime.

SECTION 3
INSTRUMENTATION AND TEST EQUIPMENT

3.1 INSTRUMENTATION SYSTEMS

The instrumentation system required in a mandatory inspection program can be defined in terms of the required measurements. The system, regardless of test regime, must include a sample handling subsystem, various measurement devices, and the appropriate readout method. The system may vary in complexity and sophistication from very complete automated versions to relatively simple manual systems.

3.1.1 Sampling System Considerations and Characteristics

Exhaust gases are extremely complex mixtures of hydrocarbons, carbon dioxide, carbon monoxide, oxides of nitrogen, aldehydes, particulates, water, nitrogen, oxygen, hydrogen and many other compounds. To accurately measure any single pollutant, or combination of pollutants, the application of proper gas sampling techniques and careful sample handling treatment prior to instrument analysis is required.

3.1.1.1 Basic Considerations - The basic consideration must be to obtain a sample of exhaust gas which is completely representative of the vehicle exhaust for the operating condition of interest. Then it is necessary to selectively remove those materials and compounds which may affect the absolute measurement of the subject pollutant without changing the concentration or characteristics of that pollutant. In a practical sense this generally means reducing the water vapor level in exhaust gases and filtering out the particulates before passing the gas sample through a measuring instrument.

This is only true when the pollutant is in the gaseous state. Hydrocarbons present one of the more difficult sampling and analysis problems because of the wide range in properties for the hundreds of hydrocarbons normally present in exhaust gas. Some of the hydrocarbons remain in the gaseous state, but some of the heavier molecular weight hydrocarbons condense in a normal sampling system and are lost from the sample. This problem of obtaining a representative hydrocarbon measurement is further complicated by their tendency to absorb (and desorb) onto certain materials with which they may come in contact in the system. Hydrocarbon condensation and absorption-desorption can result in very large errors. A properly designed exhaust gas sampling system will eliminate the likelihood of these problems occurring through the proper use of materials and sample temperature control.

Oxides of nitrogen, aldehydes, and, to a lesser extent, hydrocarbons and other exhaust compounds begin to convert to other compounds immediately following combustion in the engine. These reactions are increased in number and accelerated in rate when samples are exposed to sunlight. Delays in analysis, therefore, can result in measurements of different compounds than those originally emitted from the vehicle. Fortunately, these errors are usually small if the instrument analysis is completed within a few minutes.

Since vehicle exhaust gas contains approximately 14 percent water vapor, the gas sample is saturated at temperatures lower than about 120° to 140°F. Many of the present instruments operate at lower temperatures making it necessary to condense or chemically remove some of the water from exhaust gases prior to analysis. If this is not done, water can condense in the instruments and sampling system causing errors which will invalidate the results. Some instruments used to measure hydrocarbons, carbon monoxide and oxides of nitrogen also respond to water vapor. The water vapor concentration, therefore, must be reduced to a low level to prevent significant errors in measurement of the other compounds.

Particulates and carbonaceous material must be physically filtered from the exhaust gas prior to analysis since most instrumental methods are adversely affected by the presence of solid material in the gas sample.

As a final item of consideration in exhaust gas handling precautions, it is important to recognize that exhaust gases are poisonous, and calibrating gases such as NO are extremely toxic. Exhaust gases must be adequately vented to the atmosphere, and provisions must be made to adequately vent the calibration gases.

3.1.1.2 Dynamic Sampling - The concern for obtaining a representative sample of exhaust gas is relatively simple when steady-state modes of operation are being examined. It is simply necessary to pump a constant volume of exhaust gas through the sample conditioning system and through the measuring instrument. The problem becomes more complex if it is necessary to obtain a representative sample dynamically over several modes of vehicle operation. In this case, consideration must be given to vehicle exhaust flow rates and the varying concentrations of pollutants that exist during different operating modes. Ideally, all of the raw exhaust gas can be captured in a "bag" and a single analysis made for the pollutants of interest. This is a standard procedure in Europe, but realistically, the bag is very large and reactions between components of the raw exhaust in the bag sample compromise the measurements. The recently adopted Federal certification test procedures utilize a sampling method that collects a proportional sample of the exhaust gas along with a measured volume of ambient air. This diluted exhaust mixture then is analyzed for the pollutants of interest; a simple calculation provides a measure of the total mass emissions per mile traveled on per unit time. This procedure is scheduled for use at least through 1976. The specific procedure, including volume flow rates, is prescribed in the Federal Register (reference 16). The flow rate required results in an approximate 10:1 dilution of the exhaust gas making the instrument sensitivity 10 times more critical than for raw exhaust gas. Also the gas sampling apparatus is necessarily large (approximately 300 cfm capacity) and expensive.

3.1.1.3 Sampling Errors - In any gas sampling application, care must be exercised to avoid leaks in the sampling system. Most instruments draw the sample through sampling pumps. Leaks on the low pressure side of the pump result in "apparent" pollutant reductions which are actually analysis errors as a result of the sample being diluted. This is also true of leaks in the vehicle exhaust system which induce air into the exhaust sample. Some emission control systems involve the addition of air to the exhaust stream. These dilutions must be accounted for in the pollutant analysis to avoid erroneous conclusions about the actual mass emissions. Addition of a CO_2 analyzer or an O_2 analyzer in the analytical instrument console provides a satisfactory method for obtaining information to compute mass balance and thus correct for errors which would result from exhaust gas dilution.

3.1.1.4 <u>System Characteristics</u> - The auto exhaust analyzer to be used in a mandatory inspection program must measure concentrations of CO, HC and NO in the exhaust gases. The sampling system must provide a clean representative sample to these instruments. In defining a system for use in a mandatory inspection program, a decision must be made regarding the units in which exhaust emissions are to be measured and reported, and in which pass-fail limits are defined. All present standards, both State and Federal, are stated in mass per mile units. This is done to more directly relate the emission control program effort to air quality criteria.

On the other hand, the instruments actually measure concentration of pollutants in the exhaust gas. The conversion of these values to mass units per mile can be accomplished by multiplying the concentration values by predetermined constants based on vehicle weight, or by use of the constant volume sampling system described above.

In setting pass-fail limits in the mandatory inspection program, an alternative to the conversion of concentration units to the mass per mile standards is the direct use of concentration units. There are several advantages to this approach. If computational conversion is eliminated, pass-fail limits can be compared directly with on-line test data in a simple and/or logic system. Since no computation is required, the data processor is less expensive. Alternatively, the constant volume sampler with its attendant added expense and increased instrument sensitivity requirement is eliminated from consideration.

In the vehicle testing portion of this program, pass-fail limits for the abbreviated tests have been established in terms of concentration units. However, conversion to mass units is computed in the evaluation of the effectiveness of the various tests. This same approach is recommended for the mandatory inspection program. That is, pass-fail limits, for whatever test is recommended, be defined and measured in concentration units and that sufficient data be recorded to allow computation of mass emissions on a statistical basis.

Based on the above considerations, it is assumed that the constant volume sampling method will not be used in a general inspection system. However, it may be desirable to maintain a skeleton network of CVS units throughout the inspection system to provide quality audit checks and correlation data since all certification testing will be done by CVS procedures.

The sampling system will consist of a tail pipe probe, sample line, vapor condensor, particle trap, dual pumps, and appropriate valves for the calibration cycle and for nitrogen purging the analyzers. A schematic diagram of a typical system appears in Figure 3-1.

3.2 INSTRUMENT REQUIREMENTS AND CHARACTERISTICS

The heart of any auto exhaust emission test system is the instrument complement required to measure the concentration of pollutants in the sample. Depending on the type of test being conducted, the analysis system will vary from relatively simple and inexpensive to highly sophisticated versions. A large number of sophisticated exhaust gas analysis systems have been assembled and used in research programs and in the inspection of new cars to evaluate their compliance with State and Federal standards. At the other end of the spectrum, some relatively simple analyzers are being used by garage mechanics and tuneup technicians to assist in adjusting engine operating parameters during maintenance. The instrument system required in a mandatory inspection program lies somewhere between these extremes.

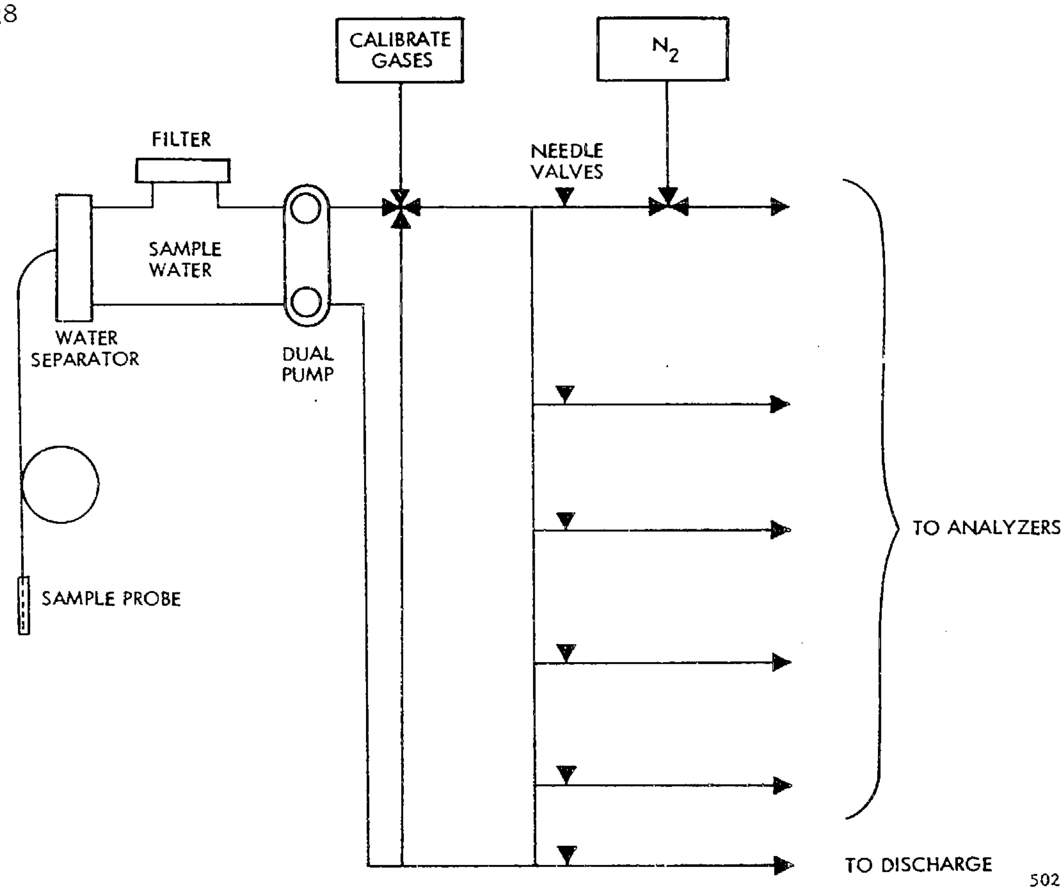


Figure 3-1. EXHAUST ANALYSIS SAMPLING SYSTEM

3.2.1 Seven-Mode, Seven-Cycle Instrumentation

The most sophisticated exhaust gas analysis systems have been designed to meet the measurement and data processing requirements of the standard seven-mode, seven-cycle test. This test requires the use of a chassis dynamometer and a well defined instrumentation and data processing system.

The analysis system consists of a sampling and calibration subsystem, five separate gas analyzers (CO, CO_2, high HC, low HC and NO), an analog-to-digital converter (ADC), a computer, and a printout device. The computer, or data processor, is programmed to accept raw data from the instruments through the ADC and to compute corrected, weighted average emission values for CO, HC and NO. Computer corrections include one for sample dilution, based on a sum of total carbon content (derived from CO, CO_2 and HC measurements). Weighted corrections are applied for each test mode based on the relative amount of time spent in each mode by an average automobile and on the relative exhaust flow rates for each mode. Weighted averages for the first four and last two cycles, as well as a weighted composite of the two groups, are reported. Arbitrary conversion of output data from concentration to mass equivalent (grams per mile) values is made on the basis of the weight of the test car.

The gas analyzers in most of these systems are based on the nondispersive infrared (NDIR) method. Sample processing includes low temperature condensation of water vapor and separate microporous filters in the sample lines of each instrument. Most systems in use incorporate a small general-purpose digital computer which provides rapid on-line reduction of raw data, and produces information for a complete report on the exhaust emission characteristics of the car under test.

3.2.2 Tuneup and Quick-Check Instrumentation

In contrast to the seven-mode seven-cycle instrumentation system, the simplest instruments presently used in auto exhaust analysis are the single and dual channel analyzers used in engine diagnosis and tuneup. These instruments are much more compact, less expensive, and easier to operate than are the large systems used for compliance inspections. At the same time, they are generally less accurate (5 percent of full scale) and some only incorporate simple panel meters which do not provide a permanent record of observed concentrations of the exhaust gases.

Widely used versions of the tuneup analyzers include single and dual channel models for CO and HC based on the NDIR principle. Others also operate on the basis of infrared absorption but incorporate interference filter wavelength selection and photoelectric detectors. Another version measures the ultraviolet emission produced by oxidation of the sample on a hot wire. This instrument includes an absorption train for hydrocarbons in the sample inlet so that the output is specific for CO. HC concentration can be roughly estimated by bypassing the HC absorber and observing total increase in output due to the HC oxidation.

Aside from the reduced accuracy, the most significant deficiency in the capabilities of these simpler instruments as mandatory inspection standards is the lack of correction for exhaust system or sample system leaks. This incapacity is relatively unimportant in the engine tuneup application because the only requirement is to observe trends or changes in gas concentrations as adjustments are made. The relative values of two readings is more important than the absolute accuracy of a single reading.

Recently, several manufacturers have announced the availability of nitric oxide analyzers whose portability and relatively low cost would place them in a category similar to the tuneup versions of the CO-HC instruments.

These NO_x analyzers (they can be made specific for NO, for NO_2 or for the sum of both) are based on the principle of electrochemical reduction or exidation of the specific pollutant. They achieve reasonable useful life and specificity by the appropriate nonaqueous solvents and electrolyte concentrations in the electrochemical cells. The electrode cells which are often supplied as plug-in modules are exposed to the sample gases through semipermeable membranes which also contribute to the specificity, the reproducibility and the life expectancy of the sensors. These instruments are, as a class, somewhat slower (30 seconds to 1 minute for 90 percent response) than NDIR analyzers. Accuracies of 2 percent full scale are claimed in ranges from a few hundred to a few thousand ppm NO_x.

Because of the strong relationship between NO and CO within practical driveability ranges, NO emission reductions can be accomplished by use of a CO measurement instrument in the repair or maintenance centers. The CO levels in exhaust gas must be used for adjustment to optimum levels of satisfactory driveability and low NO emissions (not necessarily lowest possible CO levels). Measurement of CO is necessary to identify carburetion problems and reduce lean driveability problems, but the instrument will also permit carburetion adjustment for low NO emissions.

3.2.3 Mandatory Inspection Program Requirements

The instrumentation requirements for a mandatory inspection program lie somewhere between the two extremes of seven-cycle, seven-mode equipment and tuneup equipment. Measurements required to meet current standards include CO, HC, and NO. Whether a carbon balance computation involving the CO_2 measurement is required depends on evaluation of a simpler and less expensive method for assuring quality control of the analyses. The recommended system incorporates this simpler approach, the comparison of a polarographic oxygen measurement against a preset limit of O_2 concentration.

Factors to be considered in defining instrument specifications include the required range, accuracy, speed of response, stability and ease of operation and maintenance, and the specific measurements required by each test regime.

For the standard Certificate of Compliance Inspection, no exhaust gas analysis is required. In the modified CCI procedure employed in the present program, an air-fuel ratio measurement is required. For the other inspection tests, HC and CO concentrations must be measured to meet 1966 through 1970 standards and NO concentration must be measured on all 1971 and subsequent model cars.

3.2.3.1 Carbon Monoxide - The most commonly used method for carbon monoxide (CO) measurement in exhaust analysis is the nondispersive infrared (NDIR) technique. These instruments are based on the principle that the infrared absorption characteristics of the measured gas are sufficiently characteristic for that gas, and that measurements of such energy absorption is proportional to the concentration of the compound of interest in the presence of other gases. Most commercial instruments include a hot filament as a source of IR energy, a chopper to modulate the signal, a sample cell, a reference cell, and a detector. In most versions, the detector consists of two gas-filled chambers which absorb IR energy from the sample and reference beams. The relative amount of energy absorbed in the two chambers results in a cyclic pressure difference. This results in vibration at the chopper frequency of a thin metallic membrane which separates the two chambers. The amplitude of this vibration is converted to an electrical signal, amplified, demodulated, and displayed or recorded. In the CO analyzers, other gas-filled cells may be placed in the sample and reference beams to correct the absorption of IR energy by water vapor and CO_2.

The sensitivity of the NDIR instrument is proportional to the length of the sample cell. CO monitors have been built for ambient air monitoring which can detect CO in the 1 ppm range. The sensitivity requirement for exhaust gas analysis is much less severe, since the concentrations of CO in exhaust gases are orders of magnitude higher.

On the high end, CO is occasionally observed in the exhaust gases of uncontrolled cars in concentrations above 10 percent. On the low end of the range, some properly tuned and adjusted engines on controlled cars will produce CO concentrations lower than 0.1 percent during idle and cruise modes of operation. Thus, the CO instrument should provide accurate readouts over the range of 0 to 10 percent.

Depending on the test under consideration, test failure limits will range between 1 and 5 percent CO through the 1974 model years. The instrument accuracy should be such that discriminating between passing and failing cars occurs with a probability of error of less than 5 percent. A simplified translation of this requirement is that instrument accuracy be equal to 5 percent of the failure limit. The failure limits used in the testing phase of this program are shown in Table 3-1, along with the derived requirement for instrument accuracy. The seven-mode, seven-cycle test is included in the table for completeness. The failure limit for this test is that currently prescribed for new vehicles in California.

Table 3-1. TRANSLATION OF CO FAILURE LIMITS TO ACCURACY SPECIFICATIONS

Test	CO Failure Limit (%)	Accuracy Requirement (% CO)	Accuracy Requirement % Full Scale (10% CO fs)
Seven-Cycle, Seven-Mode	1.0	0.05	0.5
Idle Test Controlled Cars	4.0	0.20	2.0
Idle Test Uncontrolled Cars	5.0	0.25	2.5
Key Mode Tests - Controlled - Idle	3.0	0.15	1.5
Key Mode Tests - Controlled - Low Cruise	2.5	0.125	1.25
Key Mode Tests - Controlled - High Cruise	2.0	0.10	1.0
Key Mode Tests - Uncontrolled - Idle	5.5	0.275	2.75
Key Mode Tests - Uncontrolled - Low Cruise	3.5	0.175	1.75
Key Mode Tests - Uncontrolled - High Cruise	3.0	0.15	1.5
Diagnostic Test - Controlled - Idle	4.0	0.20	2.0
Diagnostic Test - Controlled - 60 mph Loaded	5.5	0.275	2.75
Diagnostic Test - Controlled - 50 mph/8 hp	2.5	0.125	1.25
Diagnostic Test - Uncontrolled - Idle	7.0	0.35	3.5
Diagnostic Test - Uncontrolled - 60 mph Loaded	5.5	0.275	2.75
Diagnostic Test - Uncontrolled - 50 mph/8 hp	3.5	0.175	1.75

It is concluded that the CO analyzer required for the mandatory inspection program will require a range of 1 to 10 percent and an accuracy of 1 percent of full scale.

The response time of the NDIR analyzer is controlled by the size of the sample cell, the sample flow rate, the chopping frequency, and the damping characteristics of the electronic circuit and readout meter. For CO analyzers designed to operate in the 10 percent full scale range, typical response times of between 1 to 5 seconds for 90 percent response to a step function change in concentration are easily achieved. Since all measurements to be made on the abbreviated tests are made under steady state conditions of at least 20 seconds duration, this speed of response is adequate.

NDIR carbon monoxide analyzers are subject to error due to overlapping IR absorption bands in the absorption spectrum of water vapor and CO_2. These errors are compensated for by appropriate gas cell or solid state optical filters in the sample and reference beams. Additional protection from adverse effects of water and hydrocarbon vapor condensation and of particulate matter is provided by appropriate traps and filters in the sampling system.

The classical NDIR analyzer is reasonably stable and trouble free. Calibration and maintenance procedures are well defined and their effectiveness well established. Literally thousands of these instruments have been built by several major manufacturers. The instruments are relatively expensive however, because of the nature of the optical system and detectors. Unless carefully thermostated, the instruments exhibit excessive drift when exposed to wide variations in ambient temperature. The output as a function of sample concentration is typically nonlinear, thus requiring linearization circuits or reference to a calibration chart or stored calibration curve in automated systems.

Recently, simplified NDIR analyzers have been developed for use in engine diagnostics and tuneup applications. Some of these instruments are based on the capacitance type detector and test gas reference cell principle, but others incorporate interference filters for spectral isolation and photoelectric detectors. They have been designed for mass production at low cost. Typically, the CO versions of these instruments will have ranges of 5 to 10 percent and advertised accuracies of 2 to 5 percent of full scale. Their response times vary between 10 and 15 seconds for a 90 percent response. They all incorporate relatively simple sampling systems which include a sample pump, particle filter and water condensate trap. These simplified analyzers may not be acceptable in terms of range and accuracy (considering the accuracy requirements discussed above), and are marginally acceptable with respect to speed of response. Those with output format of an analog meter are not acceptable for the requirements of a high volume inspection program. However, they may serve as a basic model upon which improvement can be added to meet the program requirements. Specifications for the CO analyzer channel for the mandatory inspection program are summarized in Table 3-2.

3.2.3.2 Hydrocarbons - The analysis for hydrocarbons in automotive exhaust gas is complicated by several factors. As earlier discussed, hydrocarbons are a complex mixture and their concentrations vary over an exceptionally wide range. Further, it is still not agreed in the technical community whether all of the hydrocarbons should be measured, only the reactive hydrocarbons, or whether a compromise measurement of only some hydrocarbons should be done. The selection of a hydrocarbon

Table 3-2. SUMMARY SPECIFICATIONS, EXHAUST ANALYZER INSTRUMENTATION

Characteristic	Carbon Monoxide	Hydrocarbons (as n-Hexane)	Nitric Oxide	Oxygen
Range	0-10%	(1) 0-1,000 ppm (2) 0-10,000 ppm	0-2,500 ppm	0-10%
Accuracy	1% fs	1% fs	1% fs	2% fs
Repeatability	0.3% fs	0.3% fs	0.5% fs	0.5% fs
Response time (90%) (exclude sample line)	5 sec	5 sec	5 sec	5 sec
Linearity (3) (4)	Nonlinear 0.5% fs	Nonlinear 0.5% fs	Nonlinear 0.5% fs	0.5% full scale
Resolution (5) (6)	0.5% fs 0.1% fs	0.5% fs 0.1% fs	0.5% fs 0.1% fs	0.5% fs 0.1% fs
Stability - Zero - Span	2% fs/day 1% or./day	2% fs/day 1% or./day	2% fs/day 1% or./day	2% fs/day 1% or./day
Output format (7) (8)	Panel meter Dig. display + bcd	Panel meter Dig. display + bcd	Panel meter Dig. display + bcd	Panel meter Dig. display + bcd
Operating temperature range	40°-100°F	40°-100°F	40°-100°F	40°-100°F

Abbreviations: fs = full scale

or. = of reading

bcd = binary code (digital output)

Notes:

(1) Required on all tests except Certificate of Compliance

(2) Required on diagnostic test only

(3) For manual system only - manufacturer to supply calibration chart

(4) Required for semiautomated system

(5) Panel meter readout - manual system

(6) Digital readout - semiautomated system

(7) Manual system

(8) Semiautomated system

instrument must consider these factors along with all others involved in instrument selection. The NDIR technology (discussed in detail under CO analyzers, above) may be used for hydrocarbon measurements.

NDIR analyzers using detectors sensitized with n-hexane have been the standard for measurement through 1971. New Federal test procedures for 1972 and subsequent years specify the use of flame ionization detectors (FID). Niether instrument method is clearly superior and either method can be incorporated into a mandatory inspection program. Presently, the NDIR analyzer has been most successfully adapted to a relatively low-cost rugged analyzer for inspection use, but advantages of flame ionization analyzers need to be examined also.

FID instruments have one apparent advantage over NDIR analyzers in that they measure the total hydrocarbons present in a sample of exhaust gas. This eliminates the need for conversion factors and assures the measurement of all unburned hydrocarbons which are present in the exhaust gas. The FID method also can be electronically switched over a wide concentration range making only one instrument necessary in those test modes which require high dynamic range.

References to HC concentrations throughout this study are always in ppm as n-hexane. Since n-hexane is a six-carbon molecule, the same measurements could be expressed as ppm carbon by multiplying by six. Total hydrocarbon analyzers using the flame ionization principle essentially detect all of the carbon molecules (or, more properly, the bonds between carbon and hydrogen molecules) so concentrations can be expressed as ppm carbon. For the sake of consistency, FID measurement references in this study are converted to ppm as n-hexane.

The other important consideration in the selection of instrumentation is the dynamic range required to measure HC concentration in the various modes of vehicle operation. In the seven-mode, seven-cycle test, HC concentrations of a few thousand ppm are commonly observed in idle and deceleration modes - and occasional values in excess of 10,000 ppm are observed. At the same time, the 1972 California emission standard of 1.5 grams per mile of hydrocarbons is approximately equivalent to a concentration of 125 ppm for a 4500-pound car. In the testing phase, observed values of less than 50 ppm are common in the exhaust of well adjusted controlled cars operating in steady state modes.

The problem of dynamic range for hydrocarbons analysis is further complicated by a factor termed "hang-up" which is again related to the heterogeneous nature of exhaust hydrocarbons. They will tend to condense in the sampling system, resulting in errors in the measured concentration of total HC.

In the seven-mode, seven-cycle test systems, the problem of required dynamic range is met by incorporating two hydrocarbon analyzers, one with a full scale range of 10,000 ppm (1 percent) and the second with a full scale range of 1,000 ppm. This approach, rather than automatic range switching, is taken for two reasons. By its nature, the NDIR sample cell volume is optimum for a dynamic range of only about three decades of concentration. By using sample cells of different size in the two analyzers, the response over the range of interest is optimized. In addition, by use of two analyzers, the low range instrument can be switched out of the sample line and purged with nitrogen or air during those periods when high concentrations are present, thus minimizing the hang-up problem which is relatively insignificant in the high range instrument.

High hydrocarbon concentrations occur in exhaust gases of properly adjusted and maintained engines only during the deceleration mode. They are caused mainly by the presence of intake air-fuel mixtures which exceed the combustible limit and which do not ignite. Engine defects or maladjustments which can result in high hydrocarbon emissions include leaking exhaust valves, maladjusted timing resulting in misfires, and abnormally low air-fuel mixtures.

High hydrocarbon values are seldom seen during steady state modes of operation. For example, during the learning phase study of this program, in all the key mode tests only one reading in excess of 10,000 ppm was observed. All other values on both controlled and uncontrolled cars, both before and after maintenance, fell in the range of 30 to 1550 ppm. By contrast, test regimes which include deceleration modes produce observed HC values in the 10,000 ppm range. In the regimes under evaluation, the only one incorporating a deceleration mode is the diagnostic regime. Failure limits for HC concentrations during deceleration mode were established in Phase B - learning phase. They are 2000 ppm for controlled vehicles and 9000 ppm for uncontrolled vehicles. A requirement on high HC monitoring clearly exists for this test.

Considering the low end of the range, the failure limits which apply to all modes other than deceleration in the Phase B program range from 250 to 700 ppm, depending on the test. Current failure limit on the seven-mode, seven cycle test for new cars in California is 2.2 grams per mile (approximately 180 ppm). This will drop to 1.5 gpm (approximately 120 ppm) for the 1972 model-year and to 0.5 gpm (about 40 ppm) in 1975.

The current low range HC analyzer on the seven-mode, seven-cycle set has a range of 1,000 ppm full scale. Such an instrument can be supplied with 1 percent of full scale accuracy, thus providing 5 percent accuracy at the level of 200 ppm. If 5 percent accuracy is desired at the level of 40 ppm (approximate 1975 new car standard) a full scale accuracy of 0.2 percent on a 1,000 ppm instrument could be required. This is probably technically feasible since some manufacturers presently claim 0.5 percent accuracy for instruments of this type. However, it is not economically feasible since a 0.2 percent instrument could cost up to 5 times as much as a 1 percent instrument. Alternatively, the full scale range could be reduced to 200 ppm to retain the 1 percent full scale accuracy. The latter choice is unacceptable because it leaves no room for the higher fail limits which will probably be set for the mandatory simplified test. It is therefore recommended that the full scale range on the low HC instrument be set at 1,000 ppm and the accuracy at 1 percent. This will increase the probability of erroneously failing a car in terms of the 1975 standards to about 25 percent, assuming that the abbreviated test would use the same fail limit as that set for new cars. The full scale range on the high HC instruments will be 10,000 ppm. A 1 percent of scale accuracy here will provide 5 percent accuracy at the fail limit of 2,000 ppm.

The response speed of the NDIR HC analyzers is on the same order as that of the CO analyzers. The low range instruments can typically provide 90 percent response in 5 to 7 seconds, which is adequate for the proposed use. One additional feature will be required for the low HC analyzer to avoid gross errors which would result from exposing the instrument to high concentrations of hydrocarbons. This is an automatic purge or sample diversion system. Appropriate valves will be triggered when the instrument reading reaches some high percentage of the full scale reading so that the sample cell and internal sample lines will not be exposed to HC concentration above 1,000 ppm. This sample diversion will be applied only to the HC analyzer since values for the other gases must be measured during the time the HC analyzer is off stream. Although this feature will prevent accurate measurement of HC levels on some of the cars tested, it will be of no consequence since the purpose of the test is to provide pass-fail data, and the result reported will be excessively high HC concentrations. Specifications for the HC analyzer for the mandatory inspection program are summarized in Table 3-2.

There is no generally acceptable way of expressing HC reactivity and consequently no acceptable instrument for measuring reactivity or "smog-potential." The HC reactivity varies with the different HC classes. Saturates or paraffinic HC as a class are least reactive, aromatics are next, and olefins are most reactive, but there is also considerable overlap in reactivity between classes. Furthermore, the relative ranking of HC reactivity changes with the various definitions. N-hexane, for example, is more reactive than methane (which is considered almost completely non-reactive) but less reactive than aromatics such as toluene or xylenes. Until a universally acceptable scale of reactivity is defined, it is recommended that measurements in terms of reactivity not be attempted in the inspection instrumentation.

3.2.3.3 Nitrogen Oxides - Two oxides of nitrogen, nitric oxide (NO) and nitrogen dioxide (NO_2) are intimately involved in the reactions leading to production of photochemical smog. Collectively, these gases are designated oxides of nitrogen (NO_x). Nitric oxide is mainly produced in engine combustion. This compound enters the photochemical smog cycle by reacting with "reactive" hydrocarbons to produce highly toxic irritants. Aside from its participation in the photochemical smog cycle, NO_2 is a toxic substance per se.

As control methods were applied to automobiles to lower HC and CO emissions, conditions were established which resulted in increased NO emissions. The leaner and hotter burning fuel mixtures that produced low CO and HC produced higher NO. This can be partially offset by an adjustment - for example, retarding the spark - which reduces combustion temperature. Reduced compression would have similar effects. These facts, plus the clear knowledge of the part played by oxides of nitrogen in the photochemical smog cycle, have resulted in establishment of NO_x standards for new automobiles sold in California from the 1971 model-year on.

Instrumentation techniques which have been used to measure NO in exhaust gases include NDIR, nondispersive ultraviolet (NDUV) colorimetric analysis, electrochemical analysis and chemiluminescence analysis. Nitric oxide has adequate absorption in the infrared to allow the use of NDIR analyses sensitized to NO to monitor the concentration in exhaust gases. Instruments are available with dual ranges of 1,000 to 4,000 ppm and accuracies of 1.0 percent full scale.

NO is slowly oxidized to NO_2 in air. This requires that analysis specific for NO be conducted without delay in sampling. The $NO \rightarrow NO_2$ reaction can be accelerated by appropriate catalysts so that some analytical techniques are actually based on the measurements of NO_2. This includes the nondispersive ultraviolet analyzer - which in principle is similar to NDIR except that a photoelectric detector replaces the conventional microphonic detector, and the radiant source must operate at a higher temperature to produce significant energy in the near ultraviolet range.

As NO standards become more stringent, the sensitivity of the direct photometric analyses may not be adequate. Colorimetric analyses, in which the gas sample is reacted with a reagent in aqueous solution to produce a colored compound, can be made very sensitive. The classic method is that described by Saltzman (reference 17). NO must be oxidized to NO_2 before performing the analysis. This reaction has been automated. It suffers the disadvantages of all wet chemistry analyzers in requiring liquid reagents storage and handling.

The electrochemical NO_x instruments are available in ranges of a few parts per million up to several thousand parts per million. Accuracies of 2 percent of full scale are typical. Their response times tend to be longer than those of other methods.

In the chemiluminescent NO analyzer, nitric oxide is reacted with ozone to produce NO_2 molecules incorporating excited electrons. As these electrons revert to the ground state, luminescence is emitted. Under proper conditions, the amount of light is proportional to the concentration of NO in the gas stream. Practical versions of the instrument are in production. They incorporate the required ozone generator (electrical discharge), filter-photomultiplier combination necessary to isolate and detect the chemiluminescence, and the necessary electronic power supplies and signal conditioners. By appropriate range switching, these analyzers are capable of incorporating the very wide dynamic range characteristic of photomultiplier measurements. Full scale ranges of 3 to 10,000 ppm are available in a single instrument. Accuracies of 1 percent of scale are claimed, but probably not achieved, on ranges below 100 ppm.

The chemiluminiscent NO analyzers are somewhat more expensive than NDIR analyzers and they require a constant supply of tank exygen for the ozone generator. Advantages include a much faster response speed, especially on low ranges where the NDIR analyzer would require long sample cells. They are capable of better sensitivity and better accuracy on low ranges than the NDIR analyzers.

Standards for NO emission are being applied for the first time on new vehicles in California in the 1971 model-year. The standard (4 gpm) is approximately equivalent to 1,000 ppm for a 4,500-pound car. In the test phase of this program, no fail limits have been set for NO since there are no 1971 cars in this program. However, NO emission data, both pre- and post-test, have been compiled. Typical data are shown in Table 3-3. They confirm the general knowledge that pre-1966 uncontrolled cars produce significantly less NO, and that adjustments or maintenance directed at the reduction of CO and HC emissions often result in increased NO emissions.

Table 3-3. AVERAGE NO VALUES OBSERVED ON VEHICLE EMISSION TEST PROGRAM

Controlled			Uncontrolled		
	Fail			Fail	
Pass	Initial	Retest	Pass	Initial	Retest
1577	1414	1523	1323	1036	1181

Since pre-1971 cars were not designed to meet NO standards, the instrument equipment need only consider failure level standards for 1971 on. In California, these range from the 1000 to 2000 ppm requirement for 1971 standard to one-fourth this level in 1975. A recent amendment to the Federal Clean Air Act requires a 90 percent reduction in NO_x emissions from uncontrolled 1971 values. In 1976 this will result in a Federal Standard of approximately 100-150 ppm (0.4 gpm). The California failure limit for 1975 is 1.3 gpm (approximately 250 ppm). If the desired accuracy at this range is 5 percent, then a 1 percent full scale instrument would have a range of 1250 ppm. This range is not adequate to include the 1971 failure limit for some of the smaller cars. Therefore, it is recommended that a full scale range of 2500 ppm with 1 percent full scale accuracy be used. This will result in roughly a 10 percent probability of erroneously failing a 1975 model car in California.

To conduct tests in compliance with Federal Standards in 1976 may require a new instrument because of the high sensitivity required. For the present, both NDIR and chemiluminiscence instruments can be obtained in the 2500 ppm range with the required 1 percent accuracy. It is recommended that performance, rather than design specifications, be written so that the most economical technique will be incorporated into the mandatory inspection system. Specifications for the NO analyzer are shown in Table 3-2.

3.2.3.4 Sample Dilution Detection - In the seven-mode, seven-cycle test, as well as in abbreviated tests conducted in the testing portion of this program, a correction factor for exhaust dilution due to leaks or air injection systems is computed. This correction requires the inclusion of a separate CO_2 analyzer and the use of the computer in making this correction.

It would be extremely desirable from a cost standpoint to be able to compute corrections, or as a minimum, provide criteria for rejection of test data without the expense of the CO_2 analyzer and computer. Two other measurements, either of which can be made relatively inexpensively, can conceivably be used on a go/no-go basis for identifying unacceptable test data. These are the air-fuel ratio and oxygen concentration of the exhaust gas.

If low emission data were observed simultaneously with low air-fuel ratio measurements, one could conclude that the sampling system was probably leaking. Air-fuel ratio analyzers are a common component of some engine analyzer sets. They are basically thermal conductivity detectors calibrated to estimate air-fuel ratios in the exhaust gases. Most are relatively simple in design and operation, but are not very accurate.

The oxygen content of undiluted engine exhaust with air-fuel ratios up to 14 are normally less than 1 percent. If the exhaust system leaks, resulting in dilution of the exhaust gases, this fact will be evident by an increase in oxygen concentration. Since the air injection control system constitutes a deliberate dilution, O_2 concentrations of up to 4 percent are observed in these samples. Thus, separate standards of acceptability would apply to samples taken from engines equipped with the air injectors. Sufficient quantitative data are not presently available to choose the method or to state categorically that either one can provide practical decision-making information. It is therefore recommended that this be the subject of a special study to finally define a method for qualifying test data. For purposes of cost estimation the O_2 method has been included in the analysis system design.

3.2.3.5 Exhaust Gas Analysis System - Having defined the exhaust gas components required to be measured, and specified the measurement requirements in terms of range, accuracy, speed of response and other instrument characteristics, it remains to complete the design of the gas analysis system.

The system will consist of a set of four or five instruments, the related sampling subsystem and of methods for recording the data and for making the pass-fail decision. The system also includes communicating the information to the car owner and the State enforcement agency. Since, at least in the early stages, it will be highly desirable to conduct statistical analyses of the test results, the system should be designed to permanently record the data either directly in computer comparable form or in a form that allows conversion to computer format.

Two specific types of instrument systems are considered - a manual system and a semiautomatic system. The difference between the two systems lies mainly in the area of data acquisition and reporting.

3.2.3.5.1 Manual System - The manually operated system, shown schematically in Figure 3-2, is the set which is required by the Diagnostic test regime. The high range HC analyzer in this set would not be required in the system used for the Idle test or Key Mode test regimes. The sample is taken by inserting the sample probe in the auto exhaust. It passes through the water separator, which includes some heat exchange capability, to bring the exhaust gas temperature down to less than 100°F. The partially dried and filtered sample is pumped through each analyzer and rotometer type flowmeters.

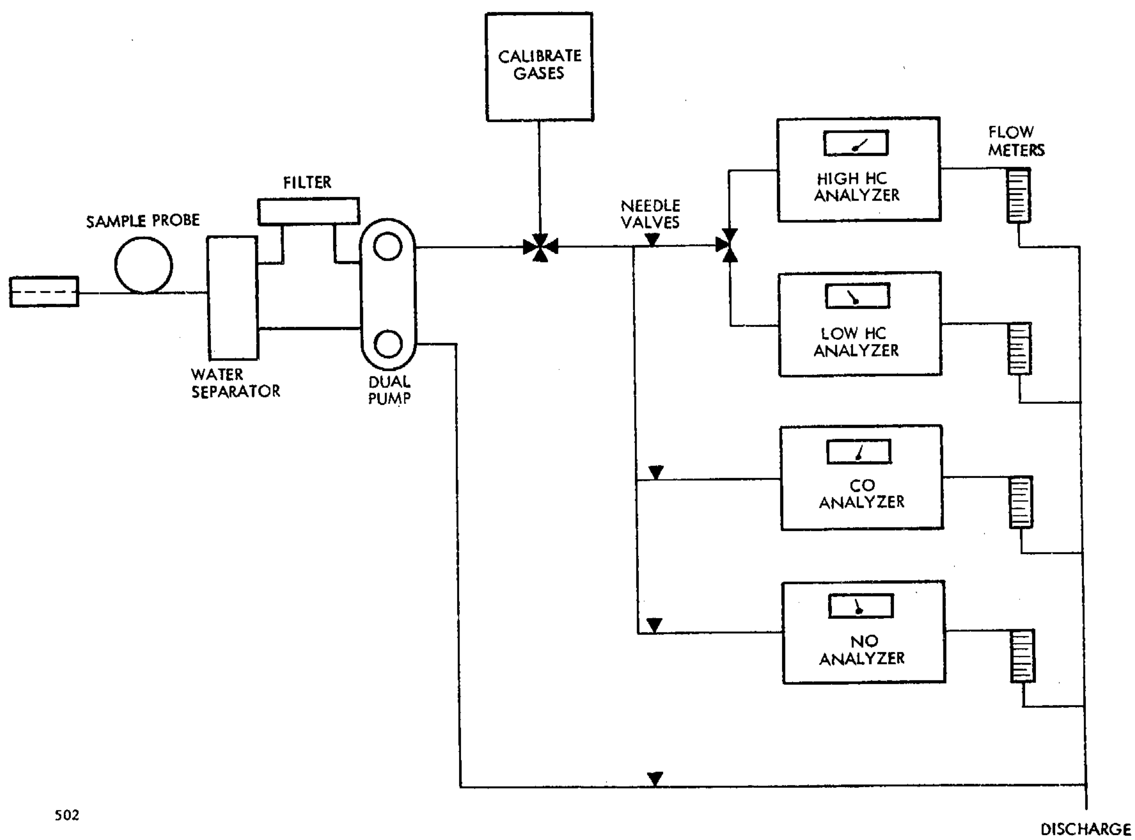


Figure 3-2. SCHEMATIC DIAGRAM OF MANUAL INSTRUMENT SYSTEM

At the appropriate time in the test, the operator manually records raw data from the meters onto a test report form. The output meters are calibrated in percent of scale (0 to 100). Upon completion of the test, he refers to the appropriate calibration charts to obtain the actual concentration of the emissions and transcribes these values to the report form. Prior to initiation of the test, the operator will have referred to a table of standards for each gas component for each test mode, as a function of the make and model of the car under test. He manually inserts these values in the form. There will be only four or five sets of standards (i.e., uncontrolled cars, controlled air injection, and two or three versions of controlled engine modifications - based on model-year), so this problem could be handled by selecting one of five preprinted forms to record the test data and prepare the report.

After recording the test results, he compares them to the standards and indicates whether the car passed or failed the test. The form with the data reproduced at the time of writing (by means of carbon interleaves or use of impression-sensitive paper) is separated into two parts, one going to the car owner and the other being accumulated and sent to a central office for key punch to get the information into computer compatible format.

Some arbitrarily chosen characteristics of this system should be mentioned because they could be modified to change the relative cost and effectiveness of the approach. They deal mainly with the signal conditioning and readout mechanisms. In the manual system, the normal condition of NDIR analyzer output is nonlinear. This requires manual reference to a calibration chart to obtain the actual concentration of the constituent for recording and comparison with the standard. In the semiautomated system discussed next, the analyzer outputs are linearized prior to digital conversion. This is an added expense, but is required to make the automated system function. The ground rule chosen to determine whether a feature, which is required in the automated system and which represents added cost, can be incorporated in the manual system is the rule of need. If the function can be performed without the added feature, it is not incorporated. A similar situation exists with respect to switching samples between the high and low range HC analyzers. This function is accomplished automatically in the semiautomated system.

One problem which is not specifically solved by the manual system is that of poor quality data due to leaking exhaust systems or instrument sampling systems. The essential result of this would be passing some cars whose emissions actually exceed the failure limits. A careful visual inspection of the entire exhaust system from engine manifold back should be accomplished on each car tested to eliminate cars with obviously leaking exhaust systems. A periodic check of the sampling system in the instrument set can be conceived and should be required of all stations using this type of system.

There are some human factors considerations which affect the overall system performance when a totally manual system is considered. The basic assumption made is that the operator will perform all tasks manually on the information provided to him through the instrumentation. The operator can degrade the instrumentation information by incorrectly reading or interpreting a display, by performing an action too slowly, or at the wrong time, by recording erroneous certification data, or by recording incorrect inspection data. Conversely, instrumentation inadequacy such as poor display resolution, nonlinearity, instrumentation saturation, poor recording formats, and a host of others can prevent the operator from taking a correct reading, action, or logging.

There are many operational conditions that can stress the operator and cause errors. These include requiring the operator to respond quickly or accurately, make complex decisions, coordinate his responses with those of the other operators, integrate information or commands from several sources, respond to inputs with potentially degrading characteristics such as rapidly changing meters, dials or digital displays, monitor displays for prolonged periods, or perform with partial or no feedback so he cannot tell if his actions are correct. At times, one stress can cause errors, at other times it is a combination of stresses that must be avoided. The problem, therefore, narrows down to the question "Can we be certain that the operator, in a manually oriented inspection structure, will follow all procedures and instructions properly?" This uncertainty is of major concern if serious consideration be given to a totally manual system.

3.2.3.5.2 <u>Semiautomatic Instrument System</u> - To provide the most rapid analysis and to reduce the probability of error, some functions of the gas analysis procedures and standard evaluation can be automated. The criteria for design of this system are to reduce the number of manual operations to a minimum and to present the output data in computer format.

<u>System Design</u> - The exhaust gas analysis system required for a mandatory inspection program will consist not only of a set of four or five instruments, but of the related sampling subsystem and data processor. The primary objective of the system design is to provide the test conductor with pass-fail data on the exhaust gas composition in specific terms of the approved standards - as represented by the approved test protocol. The information should be displayed and permanently recorded by the system. The operations required to obtain and record the data should be as few and as simple as possible. The system must incorporate easy standard methods for routine maintenance and calibration so that the maximum amount of time is available for actual testing. System response time should be as rapid as possible to meet the projected test volume rate.

<u>Instrument Set</u> - The instrumentation required in the semiautomated system is shown schematically in Figure 3-3. This particular set is required for the diagnostic test. It incorporates a high range HC analyzer to meet the requirements of the deceleration mode of this test. The sampling system is essentially the same as that required for the manual set.

The individual instruments in this set incorporate two signal conditioning features not contained in the manual system. They are linearized outputs and analog-to-digital conversion. The output of these analyzers will appear at the digital scanner in binary code, and will be expressed in concentration units rather than percent of scale. This format is required by the data processor. A bonus feature is the display of the data on the instrument section in concentration units in digital format. This feature will make it very easy for the test operator to evaluate the information and to observe any questionable readings.

The low range HC analyzer is equipped with an automatic purge valve which substitutes nitrogen for sample when the reading reaches 90 percent of full scale. In the sets used for the idle and for the diagnostic tests, this valve is reset to the sample position each time a new test or test mode is initiated. When the valve is in the purge position, a dummy signal equal to 100 percent of scale is transmitted to the data processor. In the version used in the diagnostic test regime, the output of the high range and low range HC analyzers are automatically switched in and out of

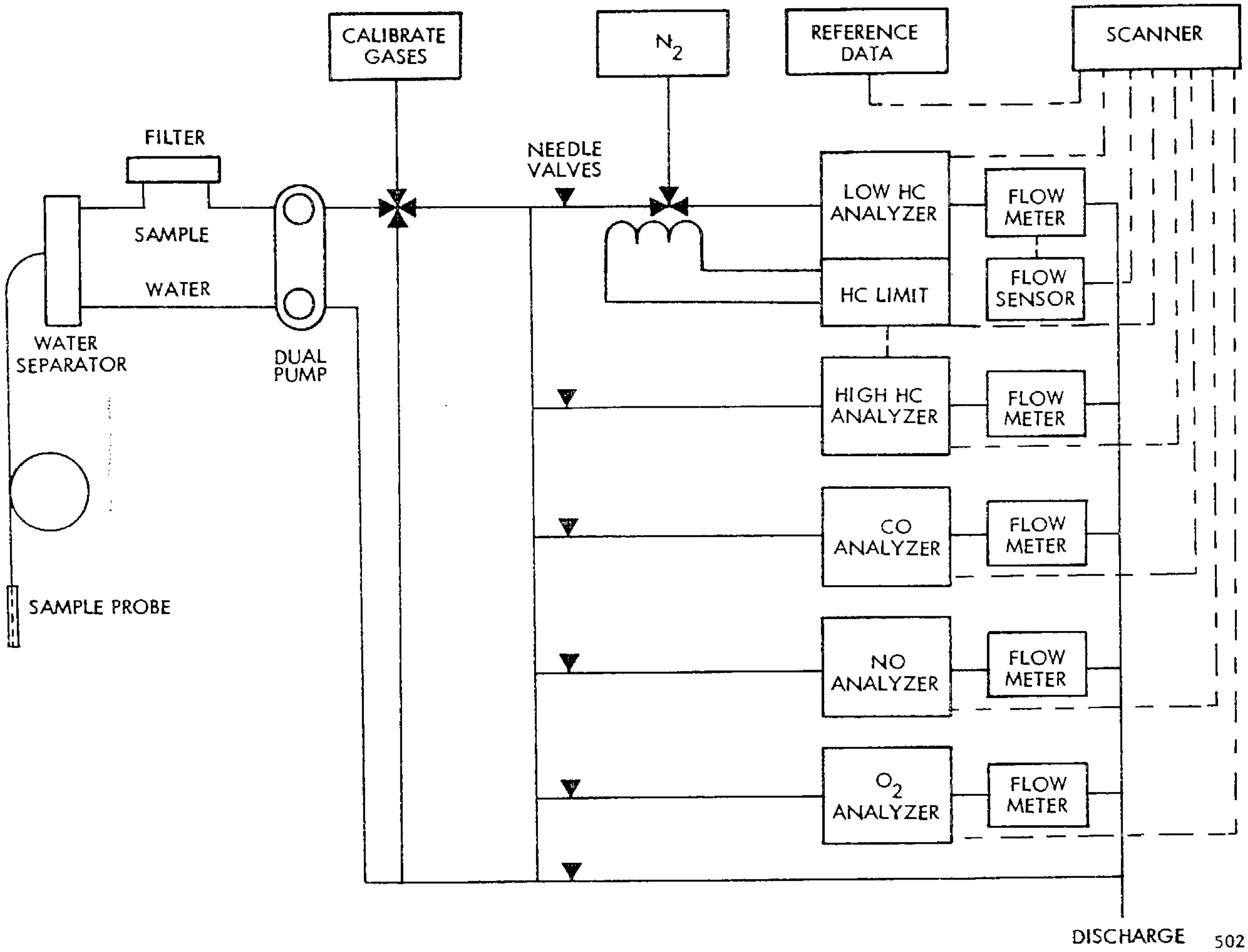


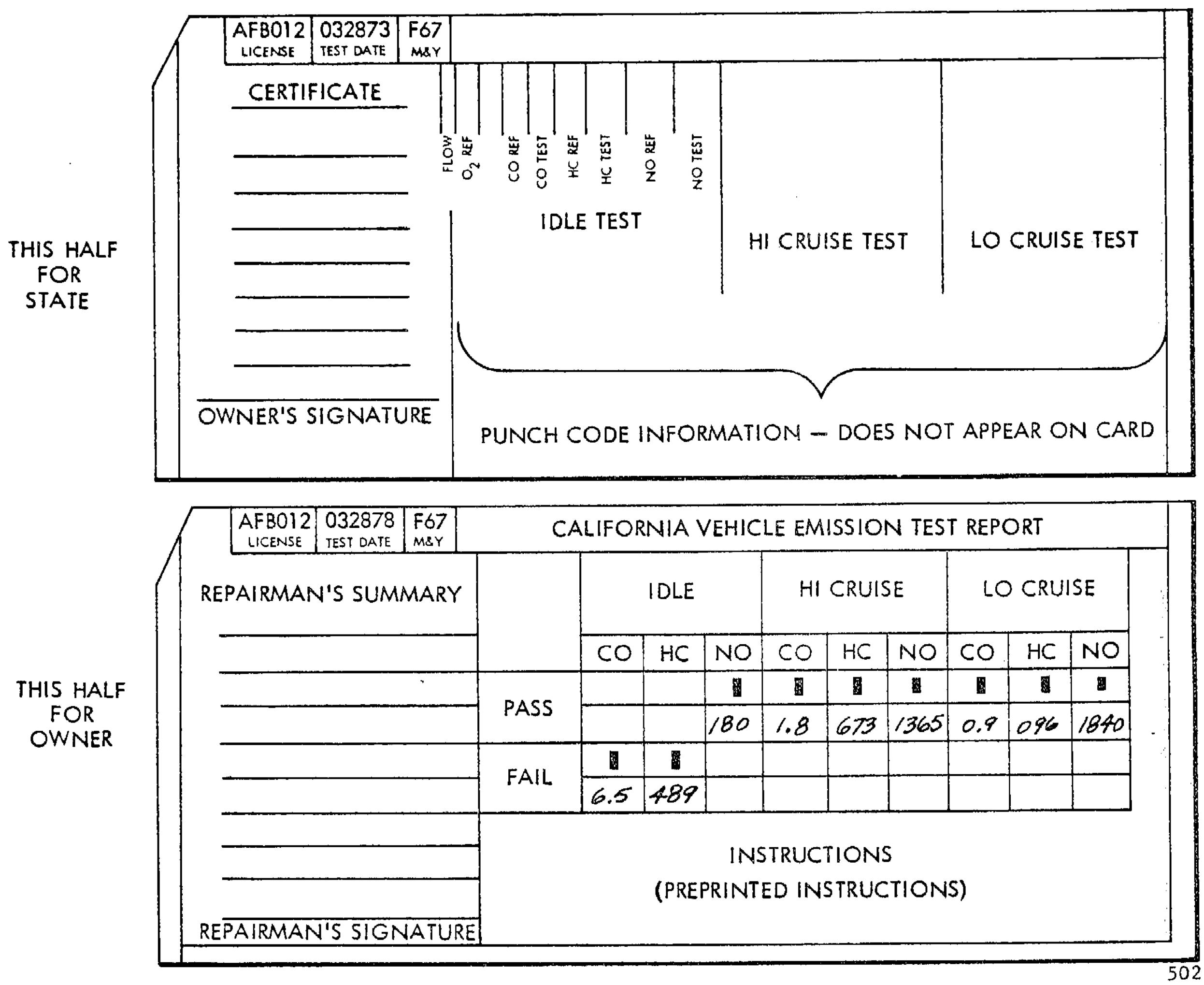
Figure 3-3. INSTRUMENTATION REQUIRED FOR SEMIAUTOMATED MEASUREMENT SYSTEM (DIAGNOSTIC TEST)

the data system, with the purge valve in the N_2 position at all times that the high range HC output is in. An oxygen analyzer is included in this set to signal high O_2 concentration to allow detection of leaking exhaust or sampling systems.

Data Processing - Two types of data must be accepted by the processor and two types of manipulations are involved. The test data which come off the instruments must be combined with other information which identifies the test subject and inserts proper test criteria and computational constants. The test data and the manipulators must be processed to produce a pass-fail decision, and the identification information must be carried through the processor and presented in the final output.

The output format may consist of a single two-part printed form, or it may include more elaborate storage and transmittance capability such as punched cards or punched paper tape. In the system presented here, the incorporation of a card punch machine which will produce a dual card report; one part for the car owner and one part for the State, is recommended. The latter will be available for filing, enforcement action, or statistical analysis. A typical format for this report is shown in Figure 3-4. Use of preprinted forms on the output and of simple alphanumeric coding of all input data precludes the necessity for a teletypewriter. The prepunched form containing owner and car identification information could conceivably be mailed to the owner to trigger his trip to the inspection station.

To retain the maximum simplicity, consistent with high quality data, a number of control functions are manual rather than based on time code or limit switching. For example, the test operator will be required to signal the mode status at that time during the test when he wishes to record data on a specific mode. Instrument calibrations will be conducted manually off-line at periodic intervals. Linearizing circuits in the analog amplifiers of the instrument will eliminate the necessity for computer calibration corrections. Averaging is not required since the pass-fail judgments are made on single point determinations. For the same reason, mode weighting computations are not required.



THIS HALF FOR STATE

AFB012 LICENSE | 032873 TEST DATE | F67 M&Y

CERTIFICATE

FLOW | O_2 REF | CO REF | CO TEST | HC REF | HC TEST | NO REF | NO TEST

IDLE TEST | HI CRUISE TEST | LO CRUISE TEST

OWNER'S SIGNATURE

PUNCH CODE INFORMATION — DOES NOT APPEAR ON CARD

THIS HALF FOR OWNER

AFB012 LICENSE | 032878 TEST DATE | F67 M&Y

CALIFORNIA VEHICLE EMISSION TEST REPORT

REPAIRMAN'S SUMMARY

	IDLE			HI CRUISE			LO CRUISE		
	CO	HC	NO	CO	HC	NO	CO	HC	NO
PASS			180	1.8	673	1365	0.9	096	1840
FAIL	6.5	489							

INSTRUCTIONS
(PREPRINTED INSTRUCTIONS)

REPAIRMAN'S SIGNATURE

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Figure 3-4. TYPICAL TEST REPORT FORM

3.3 TEST REGIME SYSTEM DESCRIPTIONS

The exhaust analysis system will vary somewhat depending on the requirements of the specific test regimes. The overall system requirements can be met with several basic modules. These are combined in various combinations to meet the test requirements. The functional modules include:

- Identification Data Module
- Test Selection Module
- Mode Status Module
- Instrument Set Module
- Data Processor Module
- Output Module.

The Identification Data Module was originally conceived as a separate unit. In the systems discussed below, however, the functions of the Identification Data Module and Output Module are both accomplished by the same system component - a standard card punch machine. This machine accepts double size punch cards. Owner and vehicle identification data may be prepunched. All other data are entered immediately prior to or during the vehicle test. A simple Data Processor Module provides the essential storage and logic functions so the system produces a two-part report which is split, one part for the owner and the other for the State agency.

The Test Selection Module establishes the required modes and related failure limits as well as the O_2 limit to qualify the test data. The Mode Status Module selects the specific failure limits for each mode in multimode tests, triggers high HC reset in the Instrument Set Module, the scanning of test and reference data and the storage of these data in the Data Processor Module, and initiates the printout when the test is complete. The Instrument Set Module provides on line exhaust gas test data as well as a sample flow indication and O_2 concentration which assure the validity of the test. The instruments in this set incorporate linearized digital outputs so that the scanner may sample the data directly with no subsequent corrections or computations required. Adequate sample flow is indicated on the Instrument Set Module so the test operator will not initiate a test unless this indicates a satisfactory condition. The sample flow signal is also inserted in the logic to trigger an abort signal if sample flow fails during a test. Such an event could occasionally result from a clogged filter on the sampling system. The other source of an abort signal would be a high O_2 signal with reference to a preset standard. This kind of abort would, in effect, direct the car owner to correct a deficiency in his exhaust system or air injection system, before the test could be completed.

The following paragraphs describe the data system requirements for each of the four test regimes under evaluation, and explain, in more detail, the functions of each module.

3.3.1 Certificate of Compliance

The basic Certificate of Compliance inspection does not require a dynamometer and requires no exhaust gas analysis instrumentation. As modified in this program, it includes not only inspection, but adjustment of engine operating parameters including air-fuel ratio. Although the latter is literally an exhaust gas measurement, the air-fuel ratio meter is ordinarily a component of engine analyzer sets rather than exhaust gas analyzers. No other exhaust gas analysis instrumentation is required for this test.

3.3.2 Idle Test

This is a single mode test. It does not require a chassis dynamometer. As in the other test regimes, the instrument set must be capable of measuring CO, HC and NO. The system must report these values along with a comparison with preset standards and a pass-fail determination. These requirements are met by the system shown in Figure 3-5. This figure includes features required in the Key Mode regime, but it also can be used to explain the Idle test version.

Identification data are punched into the two-part form before the test is initiated. All of this information except the test data may be prepunched if the mandatory inspection program is administered in a way allowing this feature. Even if most car owners have prepunched forms, there will be some cars presented for test without this prepunched form. Therefore, the on-site capability to insert this information is required.

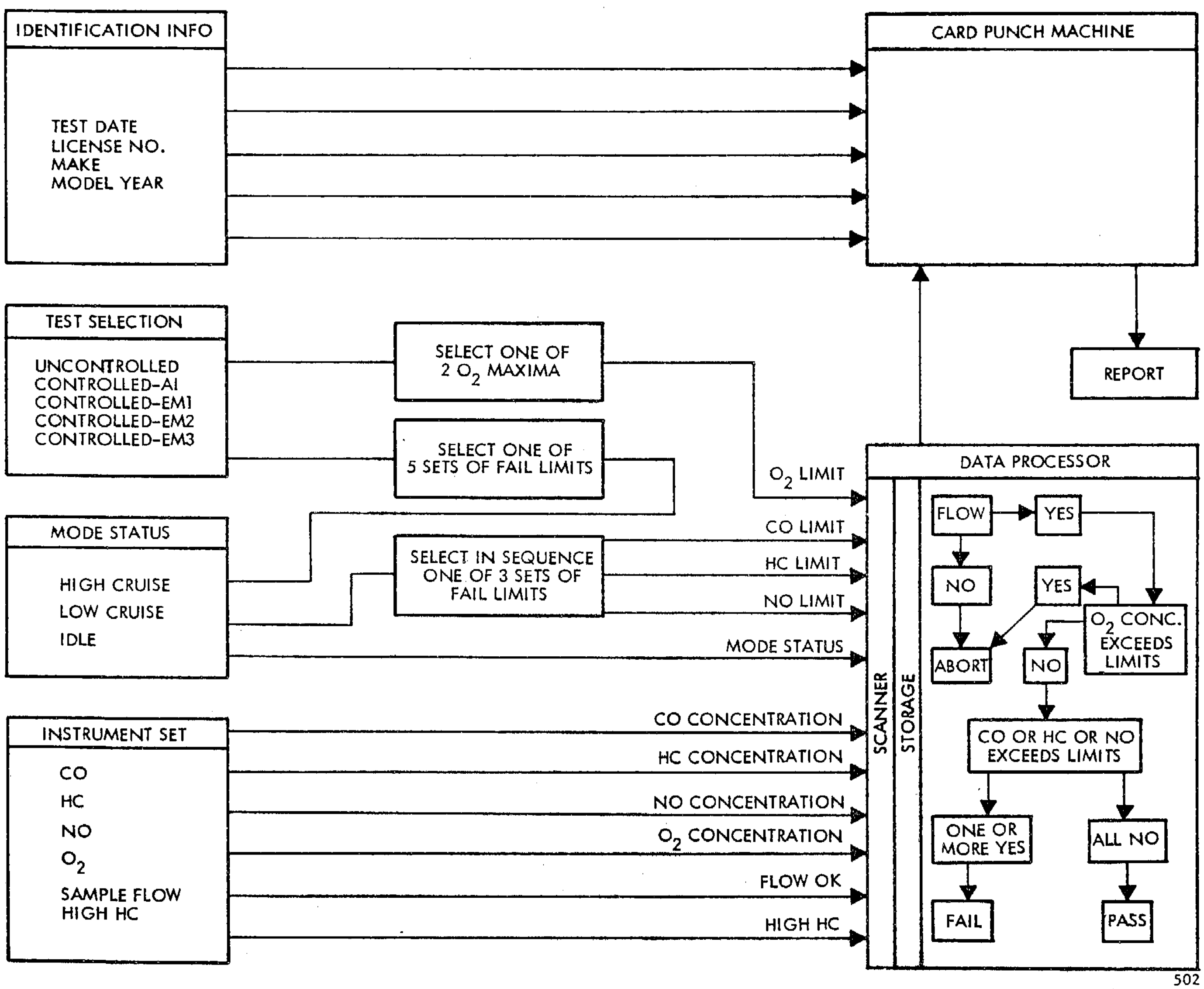


Figure 3-5. SEMIAUTOMATED EXHAUST ANALYSIS DATA SYSTEM (KEY MODE REGIME)

The test selection module selects a set of test failure limits for CO, HC and NO, based on the limits which have been set for the particular make and model of car under test. This module also selects an O_2 limit which differs only between air injector equipped cars and all others. Since the Idle test is a single mode test, no mode selector is required on this test set. The control functions assigned to the Mode Status Module in the other sets are incorporated in the Test Selection Module in the Idle Test Set. Under present standards, the test selection is actually specified and could be selected in this system by the identification of the car make and model year. This approach, however, would require a significantly more complex format for these inputs, since information on every possible type of car which might appear for inspection would have to be stored in the system.

All reference values and on-line test data are presented in digital form to a digital scanner, then stored in the data processor which contains the simple logic circuits required to assure valid test data and provide a pass-fail decision. The printout consists of a complete data and decision dump in punch card format on the State half of the two-part form and a pass-fail indication by punch position on the car owner's part of the form. If desired, the owner's printout also may include visual indication of those tests which his car failed. This information could be of value to maintenance and repair facilities in subsequent effort to bring the car into compliance.

3.3.3 Key Mode Inspection Test

The Key Mode inspection includes three steady-state test modes - idle, low cruise and high cruise. Accordingly, the test set illustrated in Figure 3-3 includes the Test Mode Status Module which is now the basic control module for individual test modes. After computing nine scanning and storage values (three components - three modes) of all test and reference data, the logic element computes a pass-fail decision and prints out the report as described above.

3.3.4 Diagnostic Inspection Test

The Diagnostic inspection test requires all the modules required for the Key Mode regime. The test modes include idle, high cruise, medium cruise and deceleration. The latter test mode will require the inclusion in the Instrument Set Module of a high HC analyzer with a full scale range of 10,000 ppm. An automatic method must be included to select the correct HC analyzer output. This function can be accomplished best in the Instrument Set Module.

On other tests, when the HC concentration exceeds 90 percent of the full scale value on the HC instrument, an "off scale" signal is inserted into the scanner. In practice, this need be nothing more than a numerical value equal to the full-scale reading of the instrument. In the Diagnostic regime test set, appropriate limit switches will present the output of the high HC analyzer to the scanner whenever the HC concentration exceeds 90 percent of the low HC full scale value. The low HC output will be switched back in automatically when the high HC value drops to 9 percent of full scale on this instrument. Thus, only one HC value will ever be presented to the logic module.

3.4 NEW TECHNOLOGY REQUIREMENTS

3.4.1 Problems of the Future

The problems associated with accurate measurement of vehicle emissions in future years will be caused by the very low concentrations of pollutants in the exhaust gas. In accordance with Federal Standards, exhaust pollutant levels in 1975 will be only one-tenth of the concentrations for similar 1970 model vehicles. Present instrumental methods approach borderline performance at the pollutant concentrations expected in 1975. By 1980 it is very likely that undiluted exhaust gas pollutant concentrations will be less than the capability of present instrumental methods to measure with satisfactory accuracy and repeatability. When vehicle emissions are measured by the EPA (Environmental Protection Agency) certification procedure, the exhaust is about 10 times diluted with ambient air prior to measurement (reference 16). For 1975 vehicles this results in the need to measure pollutants at concentrations 100 times lower than typical 1970 vehicles and 300 to 400 times lower than typical 1965 model vehicles. Using this test procedure, a mistake in measurement of only a few parts per million can represent a 50 to 100 percent error.

Mistakes in absolute measurements of extremely low pollutant concentrations can be caused by factors other than the basic measuring instruments. Mistakes can be a result of sampling errors, absorption-desorption, contamination, background levels in the ambient air, calibration gas accuracy, humidity and other environmental factors, lack of vehicle emission repeatability, and a number of other factors which are relatively unimportant considerations when measuring raw undiluted exhaust from 1971 and earlier model vehicles.

The needs for new technology must encompass all aspects of the measurement problem - not just the instrument requirements. The basic categories are as follows:

a. Vehicle emission variability

b. Ambient temperature, humidity and barometric pressure effects exhaust gas sampling

c. Sample handling methods

d. Instrument sensitivity, accuracy and repeatability

e. Calibration gases and other calibration standards.

Ignorance of any of these factors at vehicle pollutant levels which will exist in 1975 and later will essentially obviate the value of new technology developments.

3.4.2 New Instrument Technology

To measure vehicle emissions in an inspection and/or repair facility in the years beyond 1975 will require, to a large extent, a presently undeveloped instrument technology. NDIR analyzers are currently being used for HC and CO measurement applications, but very low concentrations make these instruments impractical for the future. Drift, stability and signal-to-noise ratios become intolerable. In the case of HC, other instrumental methods, such as flame ionization detection, are presently available, but are not yet adapted to the rigorous requirements of an inspection/repair environment. In the case of very low CO levels, a chemiluminescence analyzer offers promise of satisfactory performance, but this instrumental method is just out of the embryo stage of development. Problems of such things as interference effects and stability have not been solved. Gas chromatography and mass spectrometry methods offer some possibility of being adapted to a relatively low cost and reliable instrument for the inspection/repair environment, but none has been developed for such an application. NO_x measurements in future years quite probably will be made with chemiluminescence analyzers since this instrument can accurately measure very low concentrations. But as in the case of CO, this measurement approach is in an embryo stage and requires additional development effort.

Particulates, sulphur compounds, aldehydes and other exhaust pollutants which may be controlled in future years will stress instrument technology considerably beyond present knowledge. Measurement of these pollutants cannot be ignored however, because in future years the relative contribution of these presently uncontrolled pollutants may be a large percentage of the total atmospheric pollutant loading. Present R&D programs directed at the ambient monitoring application will provide significant inputs to future exhaust analysis requirements for monitoring these contaminants.

3.4.3 System Improvements

As the volume of vehicles to be tested increases and the allowed levels of contaminants decreases, the requirement for significant improvement in the sampling method is anticipated to reduce the time per analysis and increase the accuracy of each analysis. Similarly, although the initial test system will not incorporate dedicated computers, the future requirements for high volume testing will almost certainly require increased automation of data acquisition and processing.

3.5 INSTRUMENTATION SURVEY

A study was conducted to identify availability of instrumentation items as may be required for equipping of vehicle inspection/test facilities. Instrument manufacturers were requested to provide technical information and data with regard to their equipment's performance and design characteristics. A screening process was developed to aid in the evaluation of instrumentation on the basis of the data provided by the equipment suppliers. The ranking technique assigns numerical values to specific equipment characteristics. Each item selected for detailed study was than evaluated against the ranking criteria and scored accordingly. Ranked order of the equipments are presented in summary tables which identify equipment scoring results and anticipated costs. Engine analysis equipment costs have been estimated on the basis of the data submitted. Specific manufacture selections or ranking orders have not been established as the equipment studied included excessive instrumentation. The survey included information on engine test equipment and dynamometers.

3.5.1 Supplier Identification and Candidate Equipment Screening

Supplier identification and equipment screening results were reported to the State of California Air Resources Board on 1 February 1971 (Northrop Report 71Y27). The report included a description and results of the survey and screening process. The data format and glossary of data terms as provided to each candidate supplier contacted was also included in the report. At the time of report submittal, 43 equipment suppliers had responded. An additional 26 have submitted data since that time.

The report has been updated and is included as Appendix A. The equipment checklists as completed by the supplier are in Appendix B.

3.5.2 Gas Analysis Equipment

Gas analysis equipment is required for measurement of CO, HC and NO concentrations in the Idle, Key Mode and Diagnostic tests. The modified Certificate of Compliance test procedure requires a thermal-conductivity meter for air-fuel mixture measurement and adjustment. If a compliance type procedure is performed in a State inspection station, HC and CO instruments probably would be used in place of the air-fuel ratio meter.

Based on replies received during the instrumentation survey, equipments from 18 manufacturers were considered for further study. The equipments included 15 HC and CO devices, 8 CO, 4 HC, 4 NO, 3 NO_x, and 2 total HC instruments. This information was of value in estimating the cost and practically attainable performance specifications required in the instrumentation system described above.

Table 3-4 lists the specific equipment performance characteristics. Manufacturers surveyed were requested to complete a form with the particular information. To assist in preparation, a glossary of terms was provided (Appendix A). The pre-prepared data form and term definitions were distributed to encourage uniformity of the information content. In many cases, this approach was successful with data forms being completed at the desired scope and level of detail. In cases where the data were incomplete it was necessary to estimate values so equipment comparisons could be accomplished.

A ranking system has been developed to aid in equipment evaluation. Each candidate equipment characteristic, as described in the data submitted, has been evaluated against a set of ranking criteria. Criteria has been established for equipment performance features, design features, reliability maintainability, training considerations, and status and cost factors.

Table 3-5 groups the equipment characteristics according to the various features. Table 3-6 groups the equipment features by assigned item value. The value assignments are arranged to weigh the various characteristics in accordance with estimated relative importance. Table 3-6 lists the factors which are to be considered when evaluating the particular equipment features. Generally, the total score available for the feature being considered is subdivided by values assigned to the evaluation factors.

Functional capability is the most significant performance feature. Maximum functional capability values are assigned to equipments with suitable measurement value and range capability to perform the test regimes being studied. Additional credit is possible where the device appears to have application to lower level measurements as may be required by future limit values. Negative points are assigned for equipment systems which include equipment items which are not currently required.

Accuracy, reliability and initial costs are considered next in order, and assigned equal value each. Instrument accuracy is a primary judgment factor in equipment selection. Accuracies to within 10 percent are barely acceptable for current test modes. Greater accuracy is required to provide for lower level limits which will be required in the future.

Table 3-4. EQUIPMENT CHARACTERISTICS

1. Primary Use or Application
2. Status
   - A. Prototype
   - B. Production (Number Delivered to Lab and/or Garage. Years in Service)
3. Physical Description
   - A. Size (H x W x D, Inches)
   - B. Weight (Pounds)
   - C. Part of a Larger System? (Yes or No)
4. Power Requirements
   - A. AC (VAC, Hz, Amps)
   - B. DC (VDC, Amps)
   - C. Battery (Volts, Amp-Hr)
   - D. Other (Air Pressure, Water Supply, etc.)
5. Warmup Time
   - A. Initial (Minutes)
   - B. Reset, if any (Minutes)
6. Performance
   - A. Range(s) Full Scale
     - (1)
     - (2)
   - B. Overload Protection (%) (Yes/No)
   - C. Accuracy of Reading (%)
   - D. Correlation to Lab Equipment
   - E. Resolution
   - F. Repeatability
   - G. Response Time (Seconds)
   - H. Linearity
7. Calibration
   - A. Performed Once Every (Days)
   - B. Technician Time Required (Minutes)
8. Stability
   - A. Short Term (% for Hours)
   - B. Long Term (% for Hours)
9. Operating Environment
   - A. Temperature Range
   - B. Humidity Range
   - C. Shock Sensitivity (High, Med., Low)
10. Minimal Skill Level Required
    - A. Operating Personnel
    - B. Maintenance Personnel
11. Training Requirements
    - A. Operating Personnel (Hours)
    - B. Maintenance Personnel (Hours)
12. Maintainability (MTTR - Minutes)
13. Reliability
    - A. Design Goal (MTBF - Hours)
    - B. Actual (MTBF - Hours)
14. Preventive Maintenance
    - A. Performed Once Every (Days)
    - B. Special Tools Required (Yes/No, List)
15. Corrective Maintenance
    - A. Detailed Diagnostics Required (Yes/No)
    - B. Self-Test Included (Yes/No)
    - C. Parts Replaceable in the Field (Yes/No)
    - D. Special Tools, Equipment Required (Yes/No - List)
16. Cost
    - A. 1 - 10 Units
    - B. 10 - 100 Units
    - C. Over 100 Units

Table 3-5. EQUIPMENT CHARACTERISTIC RANKING VALUES

Characteristic	Item Value	Total
Performance Features		
Functional Capability	600	1150
Accuracy	200	
Resolution	50	
Repeatability	50	
Response Time	100	
Linearity	50	
Calibration Period	50	
Stability	50	
Design Features		
Calibration Technique	25	275
Operating Environment	100	
Warmup Time	25	
Power Requirements	50	
Physical Description	50	
Overload Protection	25	
Reliability Maintainability Training		
Mean Time Between Failure	200	500
Mean Time to Repair	100	
Preventive Maintenance	25	
Corrective Maintenance	25	
Skill Level Requirements	25	
Training Requirements	25	
Service/Repair Organization	100	
Status Costs		
Production Status	100	500
Initial Costs	200	
Accessory Costs	100	
Recurring Costs	100	
Total		2425

Reliability data were requested in terms of mean-time-between-failure estimates. Reliability of equipment in test station application is of particular importance, as equipment downtime will seriously affect station test capability. Most manufacturers surveyed were unable to provide reliability data in the terms desired, therefore, reliability estimates have been made on the basis of engineering judgment. Initial cost factors are extremely important as related to system implementation costs. Ranking criteria have been devised which will accommodate selection of the least expensive equipment which exhibits acceptable accuracies and reliability.

Table 3-6. GAS ANALYSIS EQUIPMENT EVALUATION SUMMARY

Order	Characteristic	Item Value	Total
1	Functional Capability	600	600
2	Accuracy	200	
	Reliability (MTBF)	200	600
	Initial Cost	200	
3	Recording Costs	100	
	Accessory Costs	100	
	Service/Repair Organization	100	
	Response Time	100	700
	Operating Environment	100	
	Maintainability (MTTR)	100	
	Production Status	100	
4	Resolution	50	
	Repeatability	50	
	Linearity	50	350
	Calibration Period	50	
	Stability	50	
	Power Requirements	50	
5	Calibration Technique	25	
	Warmup Time	25	
	Overload Protection	25	
	Preventive Maintenance	25	175
	Corrective Maintenance	25	
	Skill Level Requirements	25	
	Training Requirements	25	
	Total		2425

The third group in ranking order, which is considered to be of approximately equal value, includes recurring costs, accessory costs, service and repair organization, response time operating environment, maintainability, and production status. These characteristics generally relate to overall operating costs, equipment capability, and availability. Production status information is an important factor which provides a basis for assigning confidence levels to other equipment specifications. Equipments in limited production with minimal field operating exposure may not perform as anticipated when high production and extended usage is encountered.

Operating environment is a critical feature as laboratory type environments cannot be expected in an inspection station. For example, accuracies of NDIR equipment are largely dependent on temperature conditions at the measurement cell. Equipment which is not designed to operate within the anticipated range of temperature and humidity of a typical test station cannot be expected to maintain their measurement accuracies. With regard to operating costs, recurring costs such as filters, calibration gas and periodic preventative maintenance parts renewal are significant features when considering long range equipment usage. Maintainability, as expressed by mean-time-to-repair estimates, affects equipment downtime and subsequent station testing capability. Many design features are important to maintainability estimates.

Equipment response time is influenced by several instrument design features. Sampling system flow rates and electronic measurement response are included. Response time is of particular importance to establishing an acceptable testing rate, as the actual time required to accomplish a final measurement is the principal limiting factor in many test procedures.

Capability of the service and repair organization of the equipment manufacturer are of significant value in estimating long term operating and initial start-up costs of an inspection system. A company with the ability to provide strong field support to their products would relieve the State of the responsibility of staffing and training repair personnel.

Fourth in order of ranking consideration are resolution repeatability, linearity, calibration stability, power requirements, and physical description. Equipment resolution, repeatability, linearity, and stability must be adequate to support accuracy estimates. Power requirements are concerned with implementation costs, and the physical description influences facility space allocations.

The features which are considered fifth and last in ranking order deal with general operating features and personnel skill level, and training requirements. Calibration technique, warmup times, and preventative and corrective maintenance features influence the time expended in station operations which is not directly applied to vehicle testing. Skill level and training requirements are of importance to testing effectivity. However, they are principally implementation problems, and not considered to have recurring significance. Furthermore, little difference was found in this regard from one type of equipment to the next.

Evaluation factors to be considered in equipment ranking are listed in Table 3-7. The table is organized in order of the features as appearing in Table 3-4; these are performance, design, reliability-maintainability-training, and system status and costs. A column at the left of Table 3-7 identifies the equipment characteristic number appearing on the candidate equipments checklist which was provided the various manufacturers during the survey. The evaluation process was to study the equipment characteristics as reported on the checklist and weigh the data against the respective evaluation factor. When a decision was reached, the corresponding point value is recorded in the appropriate column on Table 3-8.

Table 3-8 lists the instruments being studied and the ranked point values in a matrix. Total scores are shown for each of the features being evaluated, including totals for all feature and associated costs.

The equipment checklists are included in Appendix B and are numbered with the same number which was assigned to the manufacturer during the survey. A second number indicates the order in which the reply was received. This mailing list/reply number is included adjacent to the equipment title at the top of Table 3-8, and if a particular checklist is desired for review, it can be located in Appendix B under that number.

Table 3-7. GAS ANALYSIS EQUIPMENT EVALUATION

Check List Number	Equipment Characteristic	Points	Evaluation Factors
1	Performance	1150	All performance features
6 A	Functional Capability	500	CO/HC/NO measurement system with suitable range capability to perform idle, key mode and diagnostic testing
		200	CO, HC or NO measurement device with suitable range capability to perform idle, key mode and diagnostic testing
		100	If capable of performing current test mode measurements and possible future lower level measurements with CVS techniques
		-100	For each measurement or major equipment item not required
E	Accuracy	200	If <1%
		100	If 1 to 2%
		50	If >2 to 5%
		25	If >5 to 10%
		0	If >10 to 15%
		-100	If >15%
E	Resolution	50	If <1%
		25	If 1 to 2%
		10	If >2 to 5%
		0	If >5%
F	Repeatability	50	If <1%
		25	If 1 to 2%
		10	If >2 to 5%
		0	If >5%

Table 3-7. GAS ANALYSIS EQUIPMENT EVALUATION (Continued)

Check List Number	Equipment Characteristic	Points	Evaluation Factors
G	Response Time	100	If 5 sec or less
		50	If 6 to 10 sec
		25	If 11 to 30 sec
		0	If >30 sec
H	Linearity	50	If <1%
		25	If 1 to 2%
		10	If >2 to 5%
		0	If >5%
7	Calibration Period (Continuous Use)	50	If 8 hours or more
		25	If 1 to 8 hours
		10	If 1 hour or less
		0	If before each measurement
8	Stability	50	If 2% in 24 hours or more
		25	If 2% in 8 to 24 hours
		0	If >2% or <8 hours
	Design	275	All design features
7	Calibration Technique	25	If optical or gas
		10	If gas only
9	Operating Environment	50	If 0 to 40°C
		25	If 32° to 100°F
		0	If >32°F or <100°F
		25	If 0- 100% RH
		15	If 0- 90% RH
		0	If below 90% RH
		25	Low shock sensitivity
		15	Medium shock sensitivity
		0	High shock sensitivity

Table 3-7. GAS ANALYSIS EQUIPMENT EVALUATION (Continued)

Check List Number	Equipment Characteristic	Points	Evaluation Factors
5	Warmup Time	25	If <10 min
		15	If 10 to 20 min
		0	If >20 min
4	Power Requirements	25	If 120V 60 Hz
		15	If other 220, DC, gas, air, etc
3	Physical Description	25	If total length, width and height <100 in
		20	If total length, width and height >100 in <150 in
		15	If total length, width and height >150 in
		25	If weight <50 lbs
		20	If weight >50 <100 lb
		15	If weight >100 lb
6 B	Overload Protection	25	If 100% or better
		15	If 50 to 100%
		0	If <50%
	Reliability-Maintainability-Training	500	All Status/Cost and Availability Features
13	Actual Mean Time Between Failure	150	If MTBF is 1000 hr or more
		100	If MTBF is 500 to 1000
		50	If MTBF is 300 to 500
		0	If <300
	Design Goal Mean Time Between Failure	50	If MTBF is 1000 or more
		25	If MTBF is 5000 to 1000
		0	If MTBF is <500
12	Mean Time to Repair	100	If MTTR is 15 min or less
		75	If MTTR is 15 to 30 min
		50	If MTTR is 30 to 60 min
		25	If MTTR is 60 to 120 min
		0	If MTTR is more than 120 min

Table 3-7. GAS ANALYSIS EQUIPMENT EVALUATION (Continued)

Check List Number	Equipment Characteristic	Points	Evaluation Factors
14	Preventive Maintenance Period (Continuous Operation)	15	If more than 24 hours
		10	If 8 to 24 hours
		5	If 1 to 8 hours
		0	If <1 hour
	Special Tools	10	If not required
15	Corrective Maintenance	25	
			Yes No
	Detailed Diagnosis		0 10
	Self-test Included		5 0
	Parts Field Replaceable		5 0
	Special Tools		0 5
10	Skill Level Requirements	25	
	Operating Personnel	15	If minimum skill and experience required
		0	If extensive training and experience required
	Maintenance Personnel	10	If minimal skills required
		0	If extensive technical training and experience is required
11	Training Requirements	25	Training Time (Hours)
			1 - 4 4 - 8 8 - 16 16 - 40
	Operating Personnel		15 10 5 0
	Maintenance Personnel		10 10 10 0
	Service/Repair Organization	100	If State wide service/repair organization exists
		50	If principal cities
		25	If large company with strong capability

Table 3-7. GAS ANALYSIS EQUIPMENT EVALUATION (Continued)

Check List Number	Equipment Characteristic	Points	Evaluation Factors
2	Production Status	100	>50 units
		75	20 to 50 units
		50	5 to 20 units
		25	1 to 5 units
		0	<5 units
	Prototype Status	100	If prototype or design stage
		25	Production prototype
		0	Breadboard
	Design Stage	10	
16	Initial Cost Per Measurement HC, CO, NO (Per Hundred Units)	100	If 300 or less
		90	If 301 to 400
		80	If 401 to 500
		70	If 501 to 600
		60	If 601 to 800
		50	If 801 to 1000
		40	If 1001 to 1200
		30	If 1200 to 1500
		20	If 1500 to 2000
		10	If 2000 to 2500
		0	If 2500 to 3000
		-10	If 3000 to 3500
		-25	If 3500 to 4000
		-50	If 4000 to 4500
		-75	If 4500 to 5000
		-100	If 5000 to 6000
		-200	If 6000 or more
	Estimated Recurring Costs Per Year (% of Initial Costs)	100	If 5% or less
		75	If 10% or less
		50	If 15% or less
		25	If 20% or less
		0	If >20% per year

Table 3-8. EXHAUST GAS ANALYSIS EQUIPMENT EVALUATION AND RANKING

Mailing List/Reply No. →		6/137	7/94	26/121	28/17				31/15	90/35						3/45 35/38	8/42	8/43	141/56				63/51	50/54	82/55	140/60			135/61	-	1-5/69	-
Equipment Item No. →		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Equipment Manufacturer / Equipment Characteristic	Maximum Ranking Points Possible	Wilks, Mira LG-1 (Variable) (CO, HC)	Panametrics (CO, HC, NO_x)	Sylvania Model 100 (HC, CO)	Bendix #1 Auto Emission Comp Controlled (CO, HC, HI HC, CO_2)	Bendix #2 Friez - CO (CO)	Bendix #1 Friez - HC (HC)	Bendix #4 EX - 2 (CO)		MSA #1 CVS Inst (CO, T/HC)	MSA #2 Monobeam (CO, HC)	MSA #3 Lira - 200 Analyzers (CO, HC, HI HC CO_2)	MSA #4 Lira - 300 Analyzers (CO, HC, NO)	MSA #5 (T/HC)	MSA #6 Lira - 200 (HC, CO, NO)	Allen/Commercial Elect Model 15-02 (CO, HC)	Autosenn Model 700 (CO, HC)	Sun Model EET-910 (HC, CO)	Olson-Horiba #1 Mexa - 200 (CO)	Olson-Horiba #2 Mexa - 300 (CO, HC)	Olson-Horiba #3 AIA - 2 (CO, HC, NO)	Olson-Horiba #4 FIA - 2 (T/HC)	Honeywell UVE - 210 (Rotunda) (CO, HC)	Environmetrics Model N-76, 0-50 PPM (NO_x)	Monitor Labs Model 42-149 (CO, HC)	Chrysler #1 Model I (CO, HC, HI HC, CO_2)	Chrysler #2 Model IA (CO, HC, HI HC, NO, CO_2)	Chrysler #4 Model II (CO, HC, HI HC, NO, CO)	Ford AMF/Thermo Electron 0-10 (NO)	Thermo Electron Model IV (CO)	Dynasciences DX - 130 0-500 PPM (NO_x)	Theta Sensors LS-800, 0-500 PPM (NO_x)
Operating Principle		Dir	Radio Chem	NDIR	NDIR	NDIR	NDIR	NDIR		NDIR/FID	NDIR	NDIR	NDIR	FID	NDIR	NDIR	NDIR	NDIR	NDIR	NDIR	NDIR	FID	UV	EC	NDIR	DIR	DIR	DIR	CI	CAL	EC	EC
Performance Features																																
Functional Capability	600	200	500	500	100	200	200	200		500	500	300	400	300	200	500	500	500	200	500	200	300	500	-	500	300	300	300	-	200	-	-
Accuracy	200	100	25	50	100	100	100	25		100	50	100	100	100	100	50	50	100	50	50	100	100	-100	100	50	200	200	200	100	200	100	100
Resolution	50	25	0	25	50	50	50	0		50	25	25	25	25	25	10	25	25	25	25	50	50	25	50	25	50	50	50	50	50	50	50
Repeatability	50	50	0	25	50	50	50	25		25	10	25	25	25	25	10	25	25	25	25	25	25	25	50	25	50	50	50	50	50	50	50
Response Time	100	100	50	25	100	100	100	50		50	50	50	50	50	50	50	25	25	50	25	50	50	0	25	25	100	100	100	100	25	0	0
Linearity	50	10	25	10	50	25	25	25		10	0	[illegible]	0	50	0	0	25	25	25	25	25	25	25	25	25	50	50	50	50	25	50	50
Calibration Period	50	-	-	10	50	50	50	50		50	50	50	50	50	50	25	25	25	25	25	50	50	25	50	25	50	50	50	50	25	50	50
Stability	50	50	-	0	25	50	50	-		50	50	50	50	25	50	0	25	50	25	25	50	25	50	50	25	50	50	50	50	25	50	50
Total	1,150	535	600	645	525	625	625	385		835	735	600	700	625	500	645	700	775	425	700	550	625	550	350	700	850	850	850	450	400	350	350
Design Features																																
Calibration Technique	25	10	10	25	10	10	10	10		10	10	10	10	10	10	25	25	25	25	25	10	10	10	10	25	10	10	10	10	10	10	10
Operating Environment	100	25	50	40	50	50	50	40		90	90	90	90	90	90	100	80	60	80	80	80	50	50	40	65	65	65	65	70	40	65	65
Warmup Time	25	25	25	25	0	25	25	25		0	25	[illegible]	0	25	25	15	25	0	25	25	0	0	15	0	15	0	0	0	0	0	25	25
Power Requirements	50	50	25	50	50	50	50	50		50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	25	25	25	25	25	50	50
Physical Description	50	50	50	50	30	50	50	50		35	50	30	30	50	50	50	50	35	50	50	50	50	50	50	50	30	30	30	50	50	50	50
Overload Protection	25	15	25	25	15	15	15	15		25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
Total	275	175	185	275	155	200	200	190		210	250	205	205	250	250	265	255	195	225	255	215	185	200	125	230	155	155	155	180	150	225	225
Reliability, Maintainability and Training																																
Mean Time Btwn Failure	200	25	50	25	50	50	50	50		50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	25	50	25	25
Mean Time To Repair	100	-	-	-	-	-	-	-		25	25	25	25	25	25	-	50	50	50	50	25	25	25	25	25	0	0	0	50	25	75	50
Preventative Maintenance	25	-	25	25	25	25	25	25		25	25	25	25	25	25	25	25	25	25	25	10	10	10	25	25	25	25	25	20	10	25	20
Corrective Maintenance	25	10	20	15	10	10	10	10		15	5	5	5	5	5	25	15	25	15	15	10	10	15	15	25	10	10	10	10	10	20	30
Skill Level Requirements	25	-	25	15	0	15	15	15		0	15	[illegible]	15	0	15	15	15	15	15	15	0	0	25	25	15	15	15	15	15	15	20	20
Training Requirements	25	-	25	15	0	15	15	15		15	15	15	15	15	15	15	15	15	15	15	15	15	15	25	25	0	0	0	5	15	25	15
Service/Repair Org	100	0	-	25	25	25	25	25		50	50	50	50	50	50	50	50	100	50	50	50	50	50	25	50	25	25	25	0	0	25	-
Total	500	35	145	120	110	140	140	140		180	185	175	185	170	180	180	220	260	220	220	160	160	190	190	215	125	125	125	125	125	215	160
Status/Cost																																
Unit Cost ($)		2,950		3,000	35,000	3,500	1,800	635		12,000	1,490	23,000	7,500	1,500	2,000	995	1,995	1,800	636	1,181	2,500	2,284	725	1,200	995	18,000	25,000	31,000	6,000	5,800	1,000	1,150
Production Status	100	25	-100	100	0	75	75	75		25	-100	[illegible]	0	30	100	100	100	100	100	100	100	100	100	100	100	25	25	25	50	100	10	40
Initial Costs	200	0	-	60	-400	0	20	60		-400	120	-400	-50	10	10	160	100	100	60	140	0	10	120	40	160	-400	-400	-400	-100	-25	40	40
Accessory Costs	100	50	-	100	100	50	50	50		0	100	100	100	25	25	100	100	100	100	100	25	25	75	25	100	100	100	100	50	50	25	25
Recurring Costs	100	100	-	100	100	75	75	100		100	100	100	100	25	100	100	100	100	100	100	100	25	100	0	100	100	100	100	75	25	0	0
Total	500	175	-100	360	-200	200	215	290		-275	220	-200	150	90	235	460	400	400	360	440	225	160	395	165	460	-175	-175	-175	75	150	75	105
Grand Total	2,425	1,220	830	1,400	600	1,165	1,185	1,010		950	1,390	780	1,240	1,135	1,165	1,550	1,575	1,650	1,230	1,615	1,150	1,130	1,335	830	1,605	955	955	955	830	825	865	840

Table 3-9 lists the equipment by item number and the scores assigned for each equipment characteristic including the total score for each piece of equipment. The equipment is then arranged in rank order according to the particular characteristics. A rank order is thus shown for CO and HC devices, CO, HC, NO, NO_x and total hydrocarbon. Total scores for the top six of the HC and CO instruments are so similar that a clear preference cannot be established. It is concluded that an adequate commercial base exists on which to levy a production requirement for exhaust gas analyzers for a mandatory inspection program.

3.5.3 Estimated Instrumentation Costs

A number of specific instruments and instrument sets for which data were received have specifications equal to those required in a mandatory inspection program. The equipment survey did not produce a specific set of instrumentation which exactly meets the requirements of any of the test regimes except the modified Certificate of Compliance inspection. For example, those combination sets which have integral sampling systems lack the required accuracy and do not include NO analysis capability.

The Sun EET-910, the Olson-Horiba Mexa 300, and the Honeywell UVE-21C are all acceptable for the Certificate of Compliance adjustments. The average price of these three instruments, each of which measure CO and HC sufficiently accurately for adjustment use, is $1235. The prices range from $725 to $1800 due to differences in performance and design features.

To estimate the approximate cost of an instrument set for the other three tests, it is necessary to estimate the cost of the various instruments and other components. These will vary somewhat, depending on the specific test regime under consideration, and whether the system is manual or semiautomated. The estimated costs for the manual and the semiautomated systems are summarized in Table 3-10. The estimates are based on the assumption that instrument sets will be procured in lots of 100 units. This assumption is not valid for the option of Idle test in Class AA private inspection stations.

3.5.4 Other Equipment

Three of the four test regimes under evaluation require the use of test equipment other than exhaust gas analyzers. These include engine analyzers for the modified Certificate of Compliance inspection and the Diagnostic tests, and the chassis dynamometer for the Key Mode inspection and the Diagnostic test.

3.5.4.1 Engine Analyzers - Requirements for engine analysis and diagnostic equipment have been identified for inclusion in the Certificate of Compliance and Diagnostic test regimes. Specific evaluation criteria for performance and cost features, such as that developed for gas analysis equipment, has not been prepared. Data received during the equipment survey did not quantify performance, design, reliability, maintainability and training features in a manner which facilitated a ranking system.

Sufficient data were accumulated to evaluate the availability and probable costs of suitable instrumentation. Generally, the available equipment contain excess instrumentation, which in some cases could be deleted, as the manufacturer supplies his equipment in modular form. If a quantity order were placed for an instrument system suitable for Diagnostic or Compliance testing requirements, it is estimated that costs would be in the order of 2000 dollars.

Table 3-9. EXHAUST GAS ANALYSIS EQUIPMENT EVALUATION AND RANK ORDER SUMMARY

Equipment Manufacturer	Evaluation Summary								Rank Order											
	Item No.	Measurement	Performance	Design	Reliability, Maintainability, and Training	Status/Cost	Total Score	Price at 100 Units	Performance	Design	Reliability, Maintainability, and Training	Status/Cost	Total Score	Unit Price	CO, HC Devices	CO	HC	NO	NO_x	T/HC
Wilks	1	CO,HC,NO	535	175	35	175	1,220	2,950	25	3	17	15	17	7	17	18	1	1	30	13
Panametrics	2	CO,HC	600	185	145	-100	830	-	26	15	16	24	19	18	19	1	6	14	31	21
Sylvania	3	CO,HC	645	275	120	320	1,400	3,000	27	16	18	19	24	22	24	5	14	20	23	
Bendix #1	4	CO,HC	525	155	110	-200	600	35,000	9	19	19	16	16	15	16	14	20	28		
Bendix #2	5	CO	625	200	140	200	1,165	3,500	17	10	24	17	15	24	15	20				
Bendix #3	6	HC	625	200	140	215	1,185	1,800	10	13	30	22	3	31	3	7				
Bendix #4	7	CO	385	190	140	290	1,010	635	12	14	22	18	10	19	10	29				
Beckman	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-				
MSA #1	9	CO,T/HC	835	210	180	-275	850	12,000	16	24	23	3	22	23	22	4				
MSA #2	10	CO,HC	735	250	185	225	1,390	1,490	19	18	10	7	12	10	12					
MSA #3	11	CO,HC	600	205	175	-200	780	23,000	24	30	12	14	18	6	25					
MSA #4	12	CO,HC	700	205	185	150	1,240	7,500	3	31	9	10	1	13	26					
MSA #5	13	T/HC	625	250	170	90	1,135	1,500	15	20	14	20	6	17	27					
MSA #6	14	CO,HC,NO	500	250	180	235	1,165	2,000	5	9	15	6	5	16	9					
Allen	15	CO,HC	645	265	180	460	1,550	995	6	11	11	5	14	14	2					
Autoscan	16	CO,HC	700	255	220	400	1,575	1,995	13	12	13	1	20	30	11					
Sun	17	CO,HC	775	195	280	400	1,650	1,800	21	5	20	23	13	21						
Olson-Horiba #1	18	CO	425	225	220	360	1,230	636	2	6	21	21	21	20						
Olson-Horiba #2	19	CO,HC	700	255	220	440	1,615	1,181	11	22	31	12	7	1						
Olson-Horiba #3	20	CO,HC,NO	550	215	160	225	1,150	2,500	20	17	2	29	25	3						
Olson-Horiba #4	21	T/HC	625	185	160	160	1,130	2,284	22	7	5	31	26	5						
Honeywell	22	CO,HC	550	200	190	395	1,335	725	28	2	6	13	27	29						
Envirometrics	23	NO_x	350	125	190	165	830	1,200	1	21	7	28	28	28						
Marquette	24	CO,HC	700	230	215	460	1,605	995	4	28	25	30	30	12						
Chrysler #1	25	CO,HC	850	155	125	-175	995	18,000	14	1	26	2	9	9						
Chrysler #2	26	CO,HC	850	155	125	-175	995	25,000	18	4	27	25	31	25						
Chrysler #3	27	CO,HC	850	155	125	-175	995	31,000	29	25	28	26	2	11						
Ford	28	NO	550	180	125	75	830	6,000	7	26	29	27	23	26						
Thermonetics	29	CO	400	150	125	150	825	3,800	23	27	3	4	29	27						
Dynasciences	30	NO_x	350	225	215	75	865	2,000	30	29	4	11	11	4						
Theta-Sensors	31	NO_x	350	225	160	105	840	1,150	31	30	1	9	4	2						

Table 3-10. SUMMARY OF COST ESTIMATES FOR MANDATORY VEHICLE INSPECTION INSTRUMENTATION

Instrument or Component	Manual System			Semiautomated System		
	Idle	K-M	Diag	Idle	K-M	Diag
CO Analyzer	$ 1,900	$ 1,900	$ 1,900	$ 2,200	$ 2,200	$ 2,200
HC Analyzer (L)	1,900	1,900	1,900	2,200	2,200	2,200
HC Analyzer (H)	NR	NR	1,900	NR	NR	2,200
NO Analyzer	2,100	2,100	2,100	2,400	2,400	2,400
O_2 Analyzer	500	500	500	600	600	600
Sampling System	2,300	2,300	2,750	3,600	3,600	3,600
Data Processor	NR	NR	NR	1,200	1,200	1,200
Card Punch Machine	NR	NR	NR	1,500	1,500	1,500
Frame and Assembly	500	500	600	900	900	900
Totals	$ 9,200	$ 9,200	$11,650	$14,600	$14,600	$16,800

Engine systems tests, accomplished during Certificate of Compliance procedures, require instrumentation capable of measuring engine ignition timing and carburetor fuel-air mixture ratio. Compliance procedures also require that engine operating parameters be verified per manufacturer's specifications and that cylinders are not misfiring. Diagnostic test regime procedures require equipment capabilities which permit fault isolation to the specific component level. System tests and measurements are performed during both dynamic and static conditions.

Eleven manufacturers responded to equipment survey inquiries. Of the 11, 6 equipment items were eliminated during the screening process. Generally, the equipment eliminated were test system components. The instruments which have been considered for selection include devices manufactured by Sun Electric, Marquette, Autoscan, Kal-Equip Company and the AC Division of General Motors. Other manufacturers are known to supply instruments of a similar type and quality. However, data were not received on these systems.

The AC instrument, known as the AC/GM Diagnostic tuneup center, and the Kal-Equip engine analyzer measure ignition output with a high voltage meter. The Sun, Marquette and Autoscan systems provide an oscilloscope display of ignition voltage. The high voltage meter technique is an adequate measurement of ignition system performance; however, oscilloscope display techniques offer several advantages, particularly when dynamic measurements are required and rapid diagnosis is desired. Oscilloscope presentations allow ignition functions to be viewed in several formats. Single cylinder firings may be selected. All cylinder firings can be superimposed or displayed simultaneously on the screen. These display options are of such significant value to effective and rapid ignition system malfunction identification that other ignition system measurement techniques are not considered adequate for use in Diagnostic or Compliance type testing. Therefore, the AC GM and Kal-Equip instruments, although inexpensive, are eliminated from further consideration.

Marquette, Sun, and Autoscan manufacture diagnostic consoles suitable for ignition system diagnosis. Each has a number of features which are unique to the particular company's diagnostic approach. Each device includes instruments for testing vehicle starting and charging systems which is not within the scope of inspection test objectives. The reported price for these analyzers thus overstates the required cost. Autoscan has designed a diagnostic feature which, although not in their production equipment, could be included for additional cost. The feature is a display presentation on the oscilloscope of a measurement which is indicative of cylinder compression. This is accomplished by measurement of starter loads during engine cranking and presentation of the load pattern on the screen.

3.5.4.2 Chassis Dynamometer - Two test regimes, Key Mode and Diagnostic, require dynamic test sequences. Key Mode procedures include 30- and 50-mph cruise measurements. Diagnostic testing requires maximum vehicle loading and decelerative HC measurements in addition to high cruise tests.

Seven chassis dynamometer manufacturers responded to the equipment survey. Of the seven, two (A. W. Tractor and Burke E. Porter) were eliminated from further consideration on the basis of excessive costs. Another company, Rawland Marine, Inc., who represents Zoellner Dynamometers of Germany, supplied preliminary data only and has not been considered further.

Three companies - Clayton, Bear and Autoscan - can provide a dynamometer which is adequate for Key Mode test procedures. The Clayton, however, is ranked highest on the basis of both cost and performance. The Bear unit was priced at $4,974.00 for 100 unit quantities, and Autoscan at $4,100.00. The Clayton Model-C-71 can be supplied for $1,975.00. With regard to performance, the Key Mode test as devised by Clayton can be performed more rapidly on a dynamometer which has an absorber with a speed power curve as on the Model C-71. The test procedure requires that the vehicle be operated first, at 48 to 50 mph with a load setting based upon vehicle weight. This process necessitates the driver accelerating the vehicle to 50 mph, setting the load, and performing the emission measurements. When the measurement is complete, vehicle speed is reduced to 30 mph. With a Clayton C-71, the absorber speed power curve is such that the absorber load at the reduced speed will not require readjustment. Other dynamometer absorber configurations would necessitate additional load adjustment and subsequent increased test time.

Diagnostic testing requires full loading tests and deceleration measurements from the 50 mph high cruise point. The Clayton C-200, Autoscan 8200 and Bear Model 1131 are acceptable dynamometer configurations with regard to performance. The Clayton cost, however, is considerably less at $3,065.00 as compared to Autoscan at $4,100.00 and Bear at $4,974.00.

These costs do not include inertial weights for simulating vehicle weight. The deceleration measurements without inertia will tend to be higher; however, it is believed that adequate diagnostic information for analysis of deceleration related components can be obtained.

SECTION 4
INSPECTION FACILITY REQUIREMENTS

The previous sections identified the functional requirements of an inspection/maintenance program and the equipment which is available to accomplish these requirements. This section describes the methodology and analysis of the station configurations, required equipment and personnel complements and vehicle test capability. Separate subsections are devoted to the following topics:

- Test Regime Procedures
- Analysis Methodology
- Test Function Analysis
- Station Functional Flow Analysis
- Facility Requirements
- Equipment Requirements
- Personnel Requirements
- Number and Distribution of Stations
- Station Operation and Program Management.

4.1 TEST PROCEDURES

Present State and Federal standards for new car exhaust emissions are based on a standard seven-mode seven-cycle test. This test requires approximately 20 minutes to complete after a 12-hour cold soak. Required equipment includes a sophisticated set of instruments and a chassis dynamometer. A number of shortened versions of auto exhaust analysis procedures have been proposed for use in mandatory inspection programs. These include the General Motors EXIT cycle, New Jersey ACID cycle, California Certificate of Compliance Inspection, Idle test, Key-Mode test, and Diagnostic test.

The effectiveness of the latter four test procedures are being evaluated with reference to a seven-mode hot-start test in phase B of this program. Because these test data are available, and comparable data for the other proposed test regimes are not, only these four are considered in the quantitative cost-effectiveness evaluation. The other test regimes fall within the limits of these four, both with respect to cost and effectiveness. Detailed descriptions of the four test regimes follow. Table 4-1 summarizes these test procedures.

4.1.1 Certificate of Compliance Inspection Procedure

Certificate of Compliance testing procedure is presently accomplished by licensed inspection stations within the State of California. The procedure is performed to verify proper operation of vehicle engines and emission control systems, and is required as a condition of vehicle ownership transfer. The test is performed with the vehicle in a static condition and is primarily concerned with assuring that the vehicle emission control equipment is operating within prescribed specification

Table 4-1. TEST PROCEDURE SUMMARY

Functions	Certificate of Compliance	Idle	Key-Mode	Diagnostic
Pretest Inspection				
Exhaust System	X	X	X	X
Engine/Fuel System	X	X	X	X
Tire Condition			X	X
Record Vehicle Data	X	X	X	X
Test Functions				
Idle rpm	CO	HC,CO,NO	HC,CO,NO	HC,CO,NO
2500 rpm		HC,CO,NO		
30 mph Cruise			HC,CO,NO	
50 mph Cruise			HC,CO,NO	
50 mph - 8 hp Cruise				HC,CO,NO
Max. Throttle Load				HC
Decel. from 50 mph				HC
PVC System Test	X			X
Exhaust Control System	X			X
Ignition Timing Test	X			X
Engine Condition Test	HC,CO			X
Ignition Timing Adjust	X			
Idle Mixture Adjust	X			

limits. The crankcase ventilation system and exhaust emission control system components are tested for functional performance. Proper engine operation is verified with diagnostic test equipment and the ignition system is observed for indications of cylinder misfire. Idle rpm is adjusted and ignition timing is reset if necessary. Idle air-fuel ratio is measured and idle mixture adjusted as required. When the engine is adjusted properly and determined to be in proper working order, a Certificate of Compliance is issued. Figures 4-1 and 4-2 illustrate the test procedure sequence. The Certificate of Compliance procedure was modified in this study to include measurement and adjustment of ignition timing and point dwell, and measurement and adjustment of air-fuel ratio.

The compliance procedure, as studied herein, considers a State inspection program in which compliance testing includes test personnel performing system adjustment and static diagnostic measurements within the inspection facility. The diagnosis is accomplished with the aid of emission measurement instruments. The inspection report data includes system performance and emission performance information. Assignment of adjustment tasks to inspection personnel is a departure from the inspection concept studied in the other test regimes. To assess the costs and facility testing capability of a compliance type procedure which does not include adjustments, station functional flow was studied with the adjustment tasks deleted from the time line analysis.

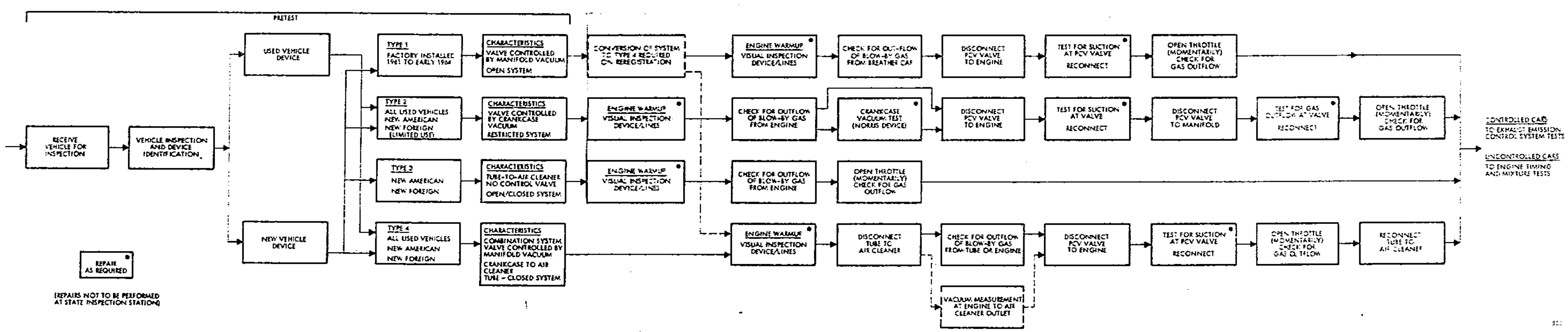


Figure 4-1. CERTIFICATE OF COMPLIANCE INSPECTION PROCEDURE CRANKCASE VENTILATION SYSTEM

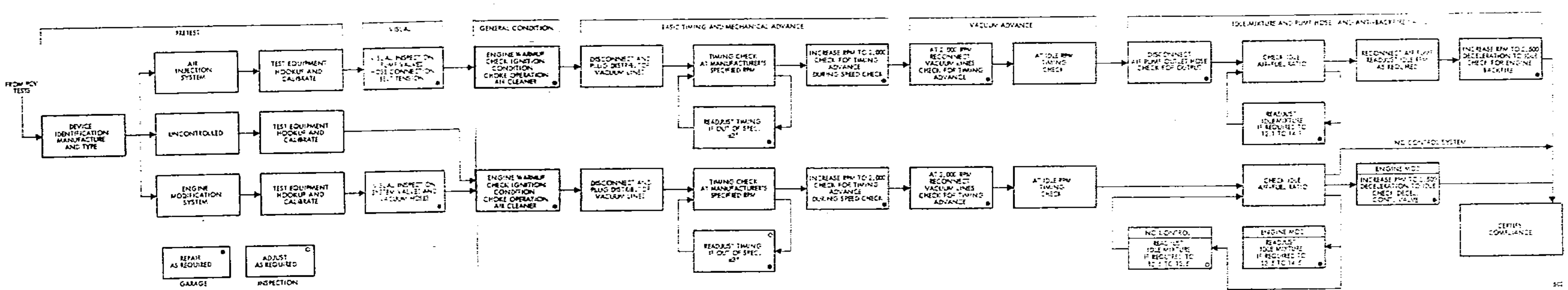


Figure 4-2. CERTIFICATE OF COMPLIANCE INSPECTION PROCEDURE EXHAUST EMISSION CONTROL SYSTEM (CONTROLLED) TIMING AND IDLE MIXTURE TESTS (UNCONTROLLED)

4.1.2 Idle Inspection Procedure

The term "idle inspection" is somewhat misleading since the vehicle is also operated at higher rpm (2500) as part of the inspection test cycle. The test mode is more accurately described as a static or light load test, as the vehicle engine is operated without benefit of vehicle road loads. It has been demonstrated that vehicle system malfunctions which result in high emission characteristics at idle rpm frequently contribute to high emissions over a typical load/speed range as measured by the standard seven-mode test. However, the sensitivity of idle testing can be improved by performing additional testing at higher engine speeds. The engine loads experienced during higher rpm operations provide an opportunity to measure effectiveness of off-idle carburetor circuits and to detect additional malfunctions that may contribute to high emissions. During the idle test procedure, engine operations and emission measurements are accomplished at 2500 rpm prior to performing idle measurements. This sequence provides the opportunity for engine temperature stabilization. Figure 4-3 shows the test procedure sequences.

4.1.3 Key-Mode Inspection Procedure

Key-Mode testing is a test process that was developed by the Clayton Manufacturing Company. The test is performed on a simple chassis dynamometer at vehicle speed and load modes that are calculated to reliably expose engine faults. The operational modes are idle, low cruise, and high cruise. After vehicle pretest activities are performed, the vehicle is positioned on the dynamometer and emission test equipment attached. The initial test mode is at high cruise conditions. The driver accelerates to a speed and load range of 44 to 50 mph and 21 to 30 hp, depending upon vehicle weight. During this period, the engine temperature is stabilized. High cruise emission measurements are performed and the vehicle speed and load is reduced to 22 to 30 mph and 6 to 12 hp depending again upon vehicle weight. After measurement, the vehicle is allowed to return to idle for final measurements prior to post-test operations.

Figure 4-4 illustrates the general test procedure. An optional full throttle maximum load mode is shown in dotted lines. This mode, if performed, would reveal certain load-related failures that the lighter load modes may not detect.

A set of repair aids has been development by Clayton in the form of truth tables. The table, when used as an inspection aid, provides diagnostic information to the repair station. In addition to the truth tables, a manual containing usage examples is provided to the repair facility.

4.1.4 Diagnostic Inspection Procedure

The diagnostic test procedure, if accomplished effectively, identifies specific component failures and allows direction to the vehicle owner to accomplish specific repair functions. This technique may result in reduced repair costs to the vehicle owner. Additionally, the longevity of engine emission control performance may be enhanced.

The test procedure includes engine load modes that tend to stress certain emission-critical components. Components that fail furing the stress conditions may be marginal under normal operating conditions. Replacement of these marginal components may preclude subsequent failure and resultant vehicle high exhaust emissions.

The vehicle for test is positioned on a chassis dynamometer. Exhaust emission measurement and engine systems measurement instrumentation is attached. The vehicle is then operated throughout a sequence of speed and load ranges that have been chosen to reveal maximum diagnostic information. Pass-fail judgments are based on exhaust emission measurements at selected points in the dynamic cycle. When the vehicle is determined to have excessive emission characteristics, additional measurements of engine systems and components performance are conducted. This process assists in determining the particular component failure causing excessive emissions.

Some system measurements can be accomplished simultaneously with emission performance testing. In many cases, superior diagnostic data can be accumulated with the vehicle and engine under dynamic conditions, and component failure decisions may be arrived at before vehicle removal from the testing position. However, at other times it will be necessary to reposition the vehicle within the facility for additional diagnostic tests.

The inspection test procedure described in Figure 4-5 includes a full throttle-full load vehicle operating mode. This mode is performed at the test beginning. Throttle position is limited to a point that will not result in transmission downshift. Load application requires judgment on the part of the test driver to preclude excess stress being applied to engine or vehicle. Vehicle age and condition must be taken into account when making the maximum load decision. The intent of this mode is to reveal ignition system failures that may result in high HC emissions. These failures involving ignition components tend to become more apparent with high cylinder pressures as experienced with high engine loading conditions. Measurements of ignition waveform with the engine scope during high loads will assist in isolating the malfunctioning component.

The high cruise test follows the full throttle mode. The high cruise point selected has been 50 mph with an 8 hp road load applied. This load speed range, when accomplished on a dynamometer capable of simulating vehicle inertia, results in an operating condition equivalent to typical high cruise operation on interurban thoroughfares. This mode is effective in measuring carburetor main circuit and power enrichment systems. Failure of carburetor-related components results in excessive CO emissions. The high cruise mode is followed by a deceleration to idle and subsequent idle measurements. Idle measurements are accomplished in the same manner as during idle inspection mode testing and with the same objectives. Measurements are made during deceleration to reveal the effectiveness of deceleration emission control system components. There are various configurations of deceleration controls on different makes of vehicles; effectiveness measurement of these devices is difficult with static testing only.

Diagnosis of failed vehicles is complicated. The variations in logic flow that stem from failure contingencies are so numerous that flow diagraming techniques become overwhelming. Figure 4-6 shows a system diagnosis function flow describing the general logic of diagnostic operations. The diagnostic tasks are divided into emission control system tests, fuel system tests, ignition system tests, and mechanical system tests. Testing for component failure within these system areas is accomplished during various static engine operating modes (off of the dynamometer). The modes are described as prestart, idle, off-idle, and special. The specific tasks that may be performed to diagnose malfunctions are shown for each system as they relate to test modes. Prestart tests generally concern detailed visual inspection of system components. Idle tests involve specific emission control components, idle speed and mixture tests and ignition timing, and point dwell inspection. Off-idle

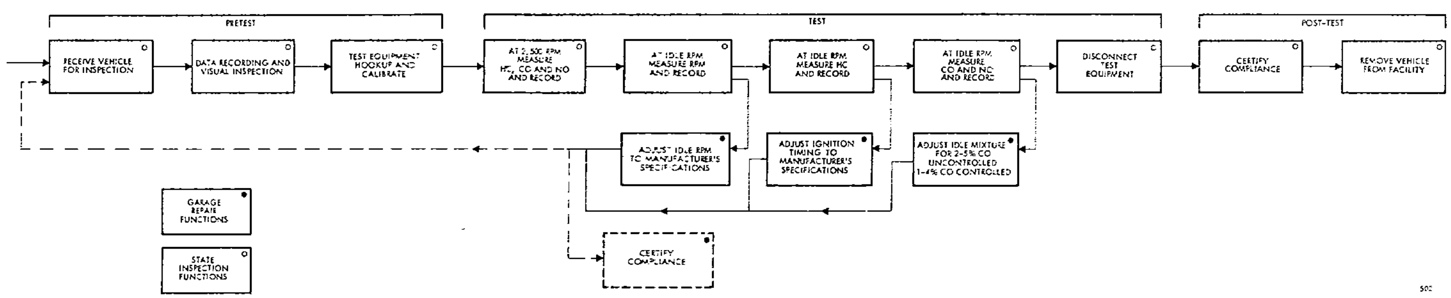


Figure 4-3. IDLE INSPECTION PROCEDURE

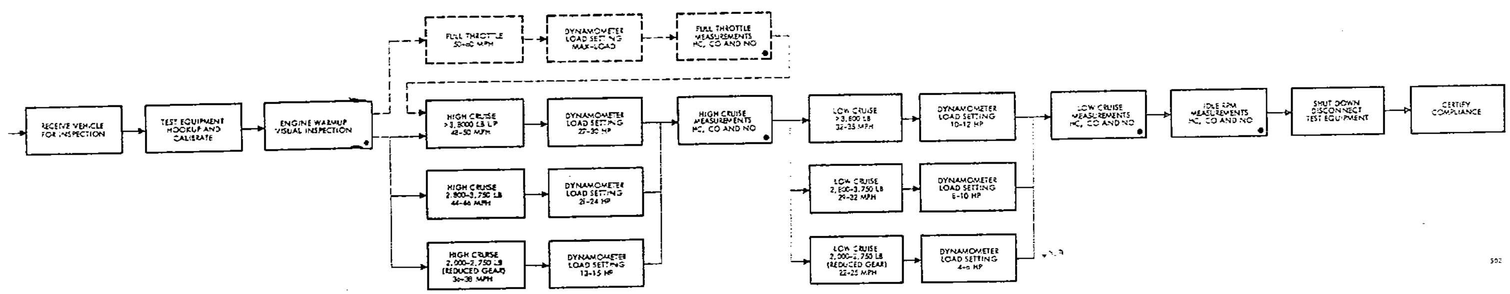


Figure 4-4. KEY MODE INSPECTION PROCEDURE

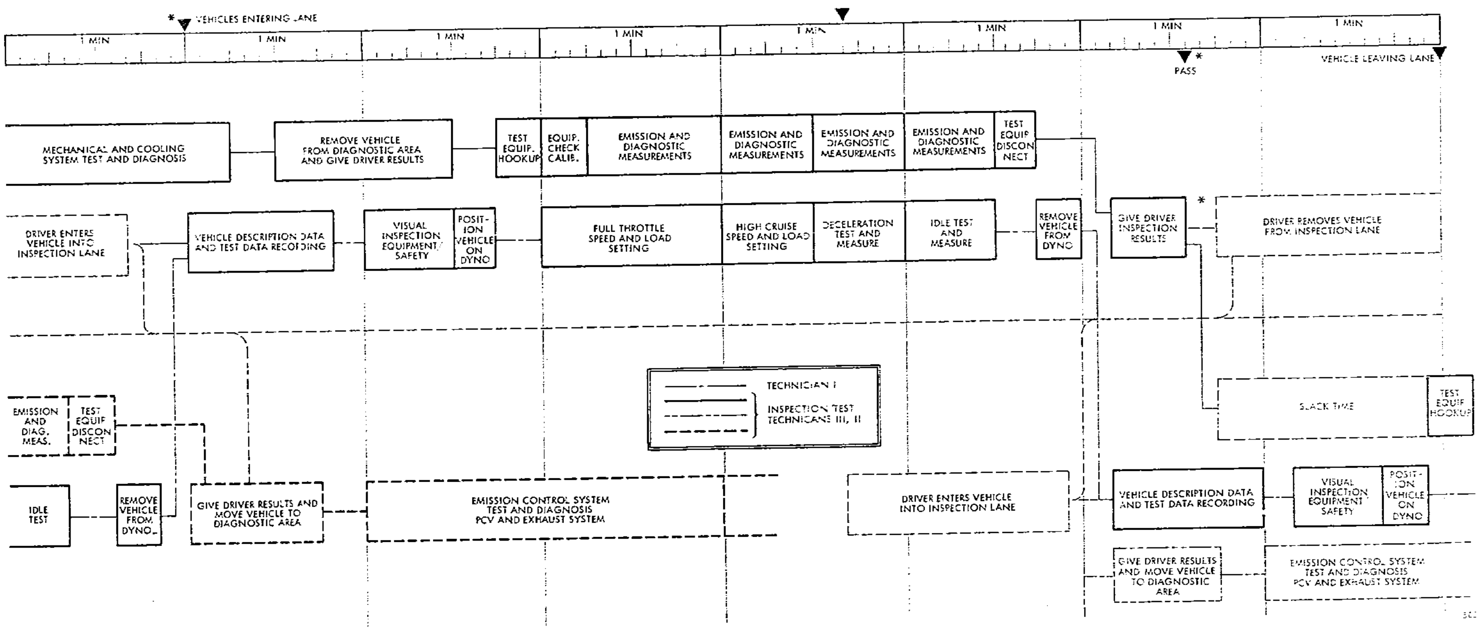


Figure 4-5. DIAGNOSTIC SINGLE LANE TEST FUNCTION FLOW

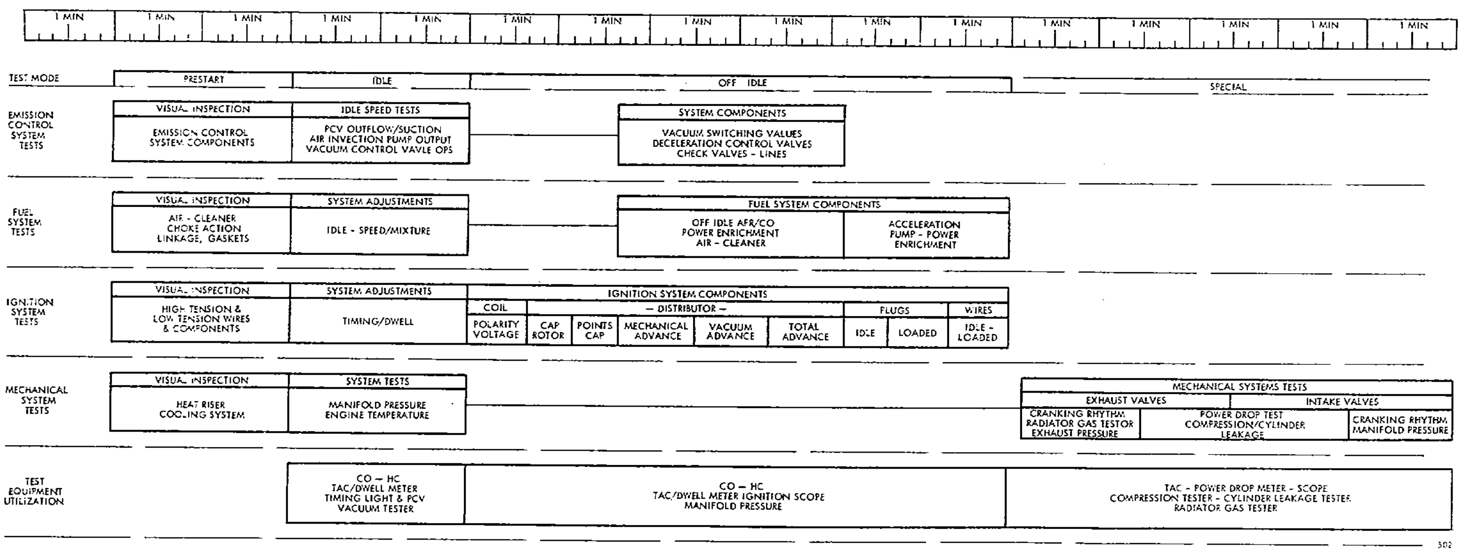


Figure 4-6. VEHICLE SYSTEMS DIAGNOSTIC FUNCTION FLOW

testing is concerned with additional fuel system tests involving air cleaners, power enrichment and main circuit carburetor condition. Ignition coil, distributor, plugs and wires are further tested, including mechanical and vacuum advance mechanisms. When mechanical systems component failure such as exhaust or intake valves are suspect, special tests involving static load (power drop) or compression testing is performed.

The functional flow as described requires a two-man test crew. One technician performs the pretest operation and places the vehicle in testing position on the chassis dynamometer. After vehicle positioning, he operates the vehicle through speed and load ranges as required by the testing procedure. Alternate procedures may be required for diagnostic purposes if failures are discovered. The other technician performs equipment hookup and accomplishes actual emission and diagnostic measurements.

The entire task can be accomplished by a single technician; however, the test time must be extended considerably. The single man procedure requires that the emission test be accomplished first, followed by dynamic diagnostic measurements as may be required for failure analysis.

4.2 FACILITY ANALYSIS AND SYNTHESIS METHODOLOGY

Definition of the equipment and facility requirements is based on analysis of the test functions. The Test Function Flow Analysis derives the test functions of each test regime against a time base. The cross utilization of equipment possible when more than one technician is assigned to a single vehicle, and the resulting time to complete the test procedure is determined. The Station Functional Flow Analysis derives the parallel functions and equipment cross utilization possible during tests of two vehicles by several technicians. The upper limit of technicians that can be effectively utilized in a test is also determined.

4.3 TEST FUNCTION ANALYSIS

Station and equipment complements are a function of the times required for each necessary function to be completed. The following sketch is a generalized time-line analysis of these required functions. The lengths of each time period are dictated by the capabilities of personnel and the characteristics of the respective equipment, including automobile and inspection procedures. It was assumed that the personnel would have the required technical skills and training to complete tasks within the limit of instrument capability. It was also assumed that the technical and operational characteristics reported by equipment suppliers were correct as stated in the equipment survey.

Test Preparation	Test Performance	Data Analysis	Post Test	(for next test) Test Preparation
t_p	t_i	t_d	t_c	t_p

These test time periods have been grouped into pretest activities, test activities and post-test activities. For Key-Mode and Idle tests, the combined pretest and post-test times require an average period of time approximately equal to that required to perform the actual inspection tests. In the Diagnostic regime, emission test failures result in vehicle systems diagnostic test actions which are more time consuming than test inspection test times. In Certificate of Compliance testing, many of the pretest functions are included in the test procedure.

Pretest includes those operations performed prior to actual emission testing and includes vehicle placement in the test lane, test equipment connections, and other preparatory activities. The pretest tasks are segmented in two parts; these are vehicle description data and test data recording, and visual inspection equipment/ safety. Fifty seconds are assigned to the vehicle description and test data recording. The task elements involve those functions required to receive the vehicle into the station and record the vehicle description data on the selected format. It is envisioned that certain conversation between the vehicle driver and test technician concerning vehicle condition and testing requirements will be conducted during that period. Results of this discussion may qualify the testing in some manner; recording of these qualifications will also be necessary. Once the data management functions are completed, the test technician inspects the vehicle to ascertain its acceptability for testing. The engine and under-hood areas are inspected for obvious component failures and safety hazards. The exhaust system is inspected to determine its suitability for subsequent emission measurement. If the vehicle is found unacceptable for testing, the driver must be provided with the reasons and rescheduled for retest when he has corrected the discrepancies. Forty seconds are allowed for the visual inspection period. The pretest and post-test time estimates, although fairly short in cases where vehicle difficulties exist, would most likely be more than adequate when the vehicles arriving for inspection are in good condition.

Test performance time, t_i, is a function of the test procedures, vehicle and driver responses, and equipment and instrumentation characteristics. Data analysis time, t_d, may vary from negligible to a significant amount, depending on the type of testing, on the data displays incorporated in the facility, and on the degree of automation in the data system. This time period also includes the time required to record any essential information for the vehicle owner's use.

Post-test times include driver consultation and removal of the vehicle from inspection area. Driver consultation time is devoted to discussing inspection and test results with the vehicle owner or his representative. During this period any further action required as determined by the testing would be explained to the responsible party.

The time line analysis establishes each test task element against a time base. The time required to accomplish these tasks was determined and then utilized to evaluate personnel and instrumentation complements. First, a given minimum instrumentation configuration was established that would provide sufficient technical capability to perform the necessary testing and emission analysis. Second, a minimum personnel complement (one or more technicians) was determined. Typical task times were then determined and a vehicle throughput rate was calculated for this minimum configuration. The personnel complement was then increased by one, new task times were developed, and a new throughput rate was calculated. This process was repeated until the limiting factor became maximum equipment utilization. When this occurred, additional equipment was added; the personnel staffing was again set at a minimum (two or more technicians) and the process was repeated. The time line analysis was conducted for each inspection test mode and includes detailed study of the inspection tasks to determine appropriate time allocations and equipment utilization schedules. Test times were determined for the pretest, test and post-test functions. Initially, the test flow of a single vehicle was studied. Then, additional personnel were considered to be available to assist in testing operations. With the additional personnel complement, task time sharing was studied to determine its effect on total test times and subsequent throughput rate improvements. Invariably, when multiple personnel were used in the test of a single vehicle, time gaps developed. These gaps resulted from particular task activities that require the attention of a single technician. In these cases, when additional assistance does not improve task efficiency or vehicle throughput, the excess personnel then become available for time assignment to other vehicles.

Test hardware utilization gaps also become apparent. When a single vehicle test flow is being considered, the test hardware becomes available for possible cross-utilization during vehicle pretest and post-test activities. This hardware availability provides the opportunity to enter additional vehicles into the time line analysis. This iterative process is then continued until personnel and test hardware utilization is determined which will effect maximum vehicle throughput rate with a single set of test hardware. This throughput rate will serve as the expression of single lane facility test capability.

4.3.1 Certificate of Compliance

Certificate of Compliance Test Function Analysis is shown in Figure 4-7. The specialized nature of the Certificate test regime requires one technician to perform all tests. Therefore, no throughput benefit resulted from double or other multiple lane configurations. Average throughput rates for controlled vehicles are 5.5 vehicles per hour if only inspection is performed, and 4.6 vehicles per hour if adjustments also are made. Throughput rates for uncontrolled cars are 10.4 vehicles per hour if only inspection is performed and 6.6 vehicles per hour if adjustments are also made. An average of 6 minutes is estimated for the pretest, general condition, and ignition measurement and adjustment tasks.

4.3.2 Idle Inspection

Figure 4-8 describes the Test Function Analysis for Idle-Mode inspection and repair functions. Pretest, test, and post-test activities are identified as being performed via a State inspection system. Repairs and adjustments are shown as commercial garage functions. During the study program, vehicles were not adjusted during inspection.

The idle inspection test tasks are shown in four sections - test equipment hookup, equipment calibration checks, 2500 rpm, and idle rpm tests and recording, and equipment disconnect. The total time allocated is 1.5 minutes with 45 seconds being devoted to test equipment hookup, disconnect and calibration tasks. These times are estimated at the maximum. The duties involved are simple and little difficulty is anticipated. The time should, on the average, take less than the time allowed. This gap will compensate for the occasions when subsequent emission measurement difficulties are experienced and excess times are experienced. As previously discussed, the high rpm measurements are accomplished first in the test cycle. This sequence provides for engine temperature stabilization prior to performing the actual idle measurements. The idle measurement time selected is 30 seconds; this is anticipated to be the average time required for the engine to stabilize at idle after deceleration and provides for average instrument response time to achieve a reliable measurement. Post-test operations involve providing the driver with testing results and removing the vehicle from the inspection facility; 45 seconds are considered to be the average post-test time. In some cases wherein the vehicle has failed to comply, the time required to explain to the driver may be lengthy. If the vehicle is successful in passing the test, the post-test time will be quite short.

The time-line analysis for a single vehicle processed through an Idle test facility indicates an average vehicle test cycle time, including pretest and post-test activities, of 3 minutes and 45 seconds. If an additional technician is added and cross-utilization of the testing instrumentation is employed, the throughput rate can be doubled.

4.3.3 Key-Mode Inspection

The Test Function Flow Analysis for Key-Mode station is shown in Figure 4-9. The Key-Mode test can be accomplished by a single technician. In this case, the inspection technician would perform the pretest, test, and post-test tasks. The total test time experienced is estimated at 5 minutes and 15 seconds. The Key-Mode test, exclusive of test equipment hookup and disconnect, is estimated at 1.5 minutes, with 30 seconds being allowed for each mode. Analysis of test operations, while being conducted with a single technician, reveals substantial equipment utilization time gaps. When a single lane personnel complement includes two technicians, the throughput rate is essentially doubled. One technician is scheduled to perform the pretest and post-test duties and the other one performs the actual Key-Mode emission test. The vehicle owner is directed to a waiting area where he remains until the test is complete. The technician then returns the vehicle and explains the test results and repair options.

4.3.4 Diagnostic Inspection

Figure 4-5 identifies tasks performed during the emission testing cycle. The entire Diagnostic test can be performed by one diagnostician. This causes considerable free equipment time, particularly when failure requires system diagnosis. Successively adding personnel to completely utilize one equipment complement shows that the dynamometer is fully utilized for inspection testing when four inspectors are assigned to the test and diagnostic functions. Three inspectors are involved in operations related to pretest, test, post-test, and system malfunction diagnosis, and one inspector is utilized to drive the vehicle during the cycles. This functional flow for the four-man complement represents most effective utilization of equipment and is shown in Figure 4-5. Figure 4-6 shows the diagnostic functions which must be performed. The system diagnosis functions are conducted by one diagnostician. No equipment cross-utilization is possible if more diagnosticians are assigned to one vehicle because measurements of the various engine systems are made simultaneously by one technician. Average test time for the inspection process is 9 minutes for a four-man station. Diagnosis of system failure requires an additional 20 minutes resulting in average overall inspection and diagnosis time requirement of about 30 minutes for a vehicle failing the inspection. Assuming average failure rate of 50 percent, the overall average vehicle throughput rate is 12 vehicles per hour per lane.

4.4 TEST STATION FUNCTIONAL FLOW ANALYSIS

A facility functional flow and test capability analysis is conducted to arrive at estimates of facility testing capabilities with single and double lane equipment and personnel complements. Test time data, which have been calculated during the preceding time analysis, provide the basis of functional flow assessments. Station

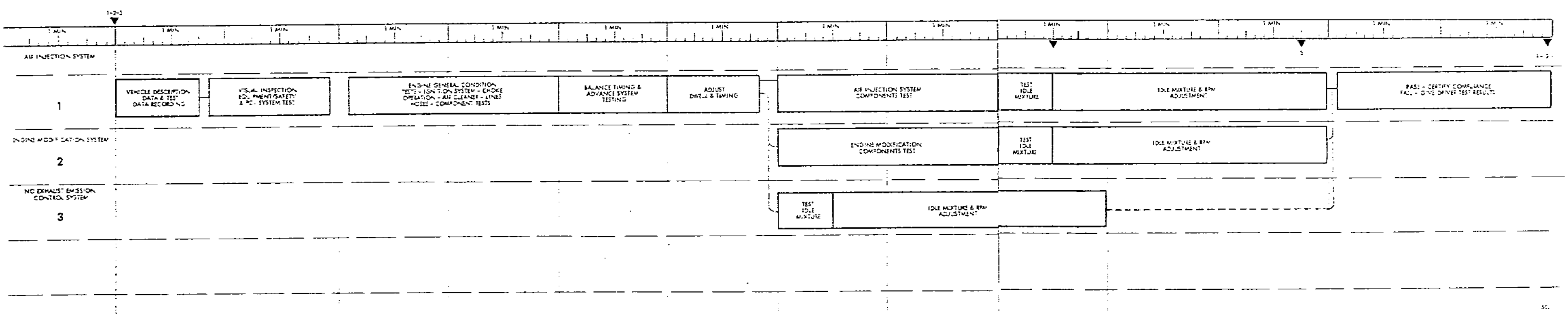


Figure 4-7. CERTIFICATE OF COMPLIANCE
SINGLE LANE TEST FUNCTION FLOW

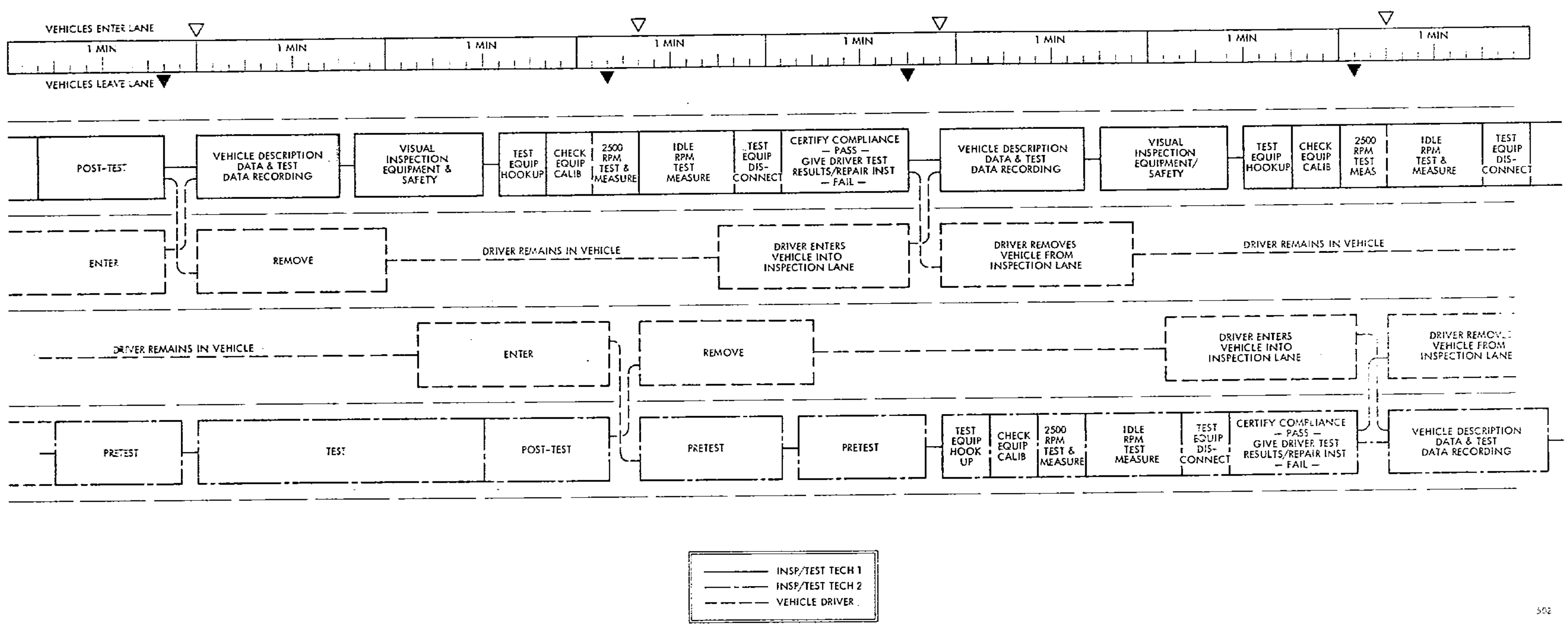


Figure 4-8. IDLE MODE SINGLE LANE TEST FUNCTION FLOW

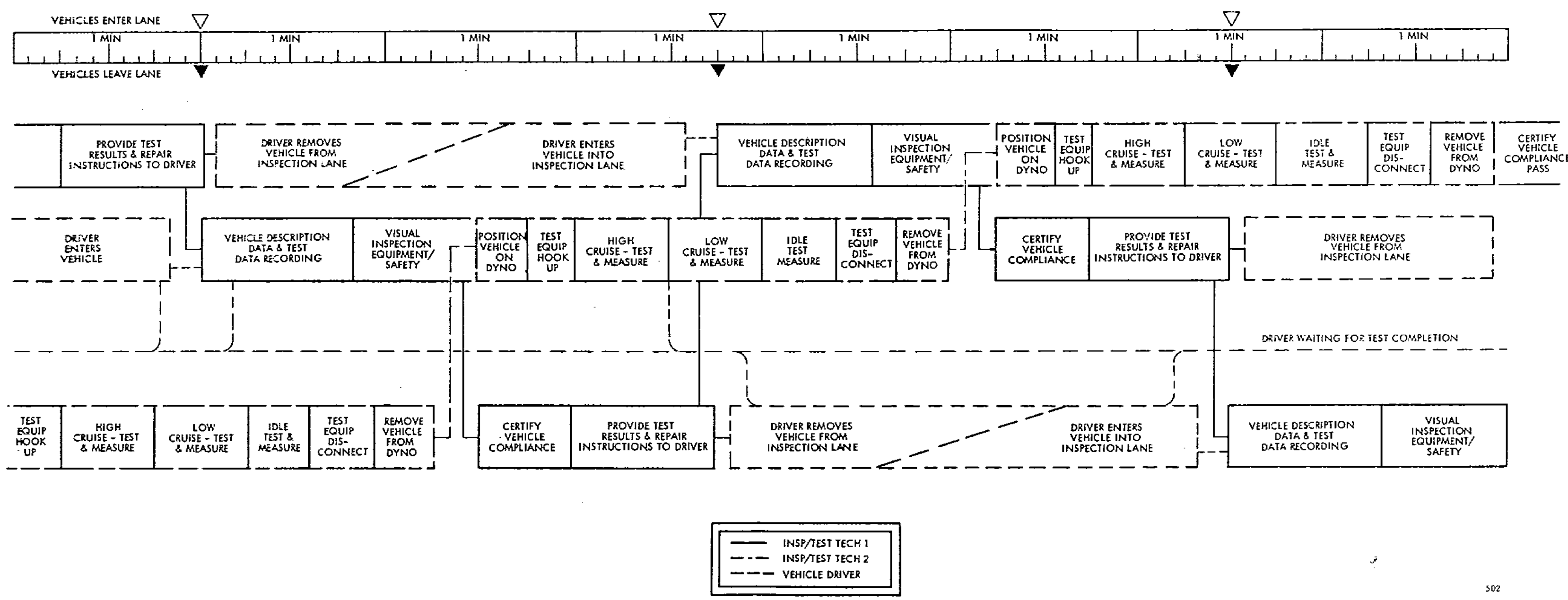


Figure 4-9. KEY MODE SINGLE LANE TEST FUNCTION FLOW

functional flow charts are developed (Figures 4-10, 4-11, and 4-12) which display the testing activities against a time base. However, in this case, the individual testing elements have been assembled into three time blocks. The time blocks represent the total time required for pretest, testing, and post-test functions. Station functional flow analyses of Idle, Key-Mode, and Certificate of Compliance testing are relatively straightforward with station testing capability being expanded as personnel complement is increased. However, in the case of the Diagnostic type station, station functional flows become more involved as alternate vehicle pass-fail rates are considered. On each functional flow chart, a summary table is provided. These summary tables identify station testing capabilities with various personnel and equipment configurations. Vehicles per hour, vehicles per minute, and the average man-minutes expended per vehicle is listed for single and double lane configurations with minimum to maximum test crew complements. Pretest and post-test times also are summarized for an individual vehicle test. Table 4-2 summarizes average test times and vehicle throughput rates for each test regime.

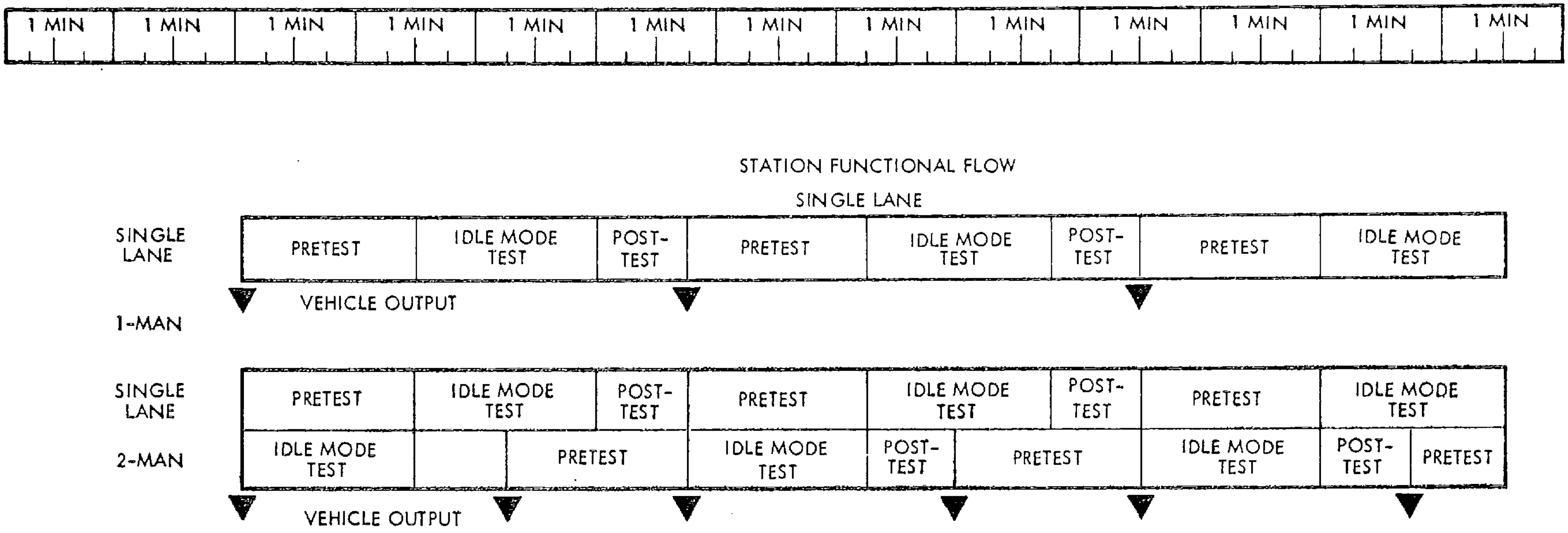
The analysis methodology was applied to a modularized concept of a complete single lane inspection facility able to process one vehicle at a time. Any larger throughput capability can be determined by appropriate combinations of the single and double lane configurations. Since the equipment and personnel requirements of a double lane are not necessarily twice that of the single lane configuration, each test regime has been analyzed for both cases. By evaluating the time-line analysis, cross-utilization of both hardware and personnel can be shown to occur, resulting in more efficient application of the test system elements in double lane stations than in single lane stations. No further cross-utilization was feasible in stations larger than two lanes.

The single lane configuration is comprised of the minimum equipment and systems required to conduct a particular test cycle, and of the minimum personnel staff necessary to realize maximum utilization of the hardware employed. Determination of minimum hardware requirements was aided by the analysis of past studies, by communications with field personnel, by consultation with Air Resources Board personnel, and by the above engineering analysis. Maximum utilization of equipment was determined by the previously mentioned operational and time-line analyses. Once the single lane configuration was designed (after many iterative changes), the two lane configuration was designed.

The basic inspection facility requirements were determined for the different station configurations. Facility size recommendations were based on vehicle flow, equipments and system placement, driver waiting areas, utilities areas, and station access. The major elements leading to a detailed station design were determined with the aid of Industrial Engineering personnel at Northrop.

4.4.1 Certificate of Compliance Station Flow Analysis

Certificate of Compliance functional flow is represented by Figure 4-7. Time-line analysis of compliance test function has not revealed any clear advantages in equipment cross-utilization concepts, therefore additional flow diagramming of station functional operations was not necessary. Testing capability for a single lane involves the tasks as performed by a single technician. Double lane capability is achieved by adding another man and equipment set. Facility testing capability depends upon the engine adjustment policy. If engines are to be adjusted during the inspection process, the facility throughput rate for single lane is 4.1 vehicles per hour. If adjustment is deferred and assigned to the repair level, throughput improves to 7.7 vehicles per hour.



STATION FUNCTION FLOW SUMMARY TABLE

	SINGLE LANE		DOUBLE LANE	
VEHICLES PER HOUR	17	34	51	68
AVG TIME PER VEHICLE (MIN)	3.75	1.8	1.25	.9
SLACK TIME PER HOUR	0	0	0	0
TEST CREW SIZE	1	2	3	4

PRETEST TIME	1.5
TEST TIME	1.5
POST-TEST TIME (PASS)	.25
POST-TEST TIME (FAIL)	1.25
POST-TEST TIME (AVERAGE)	.75

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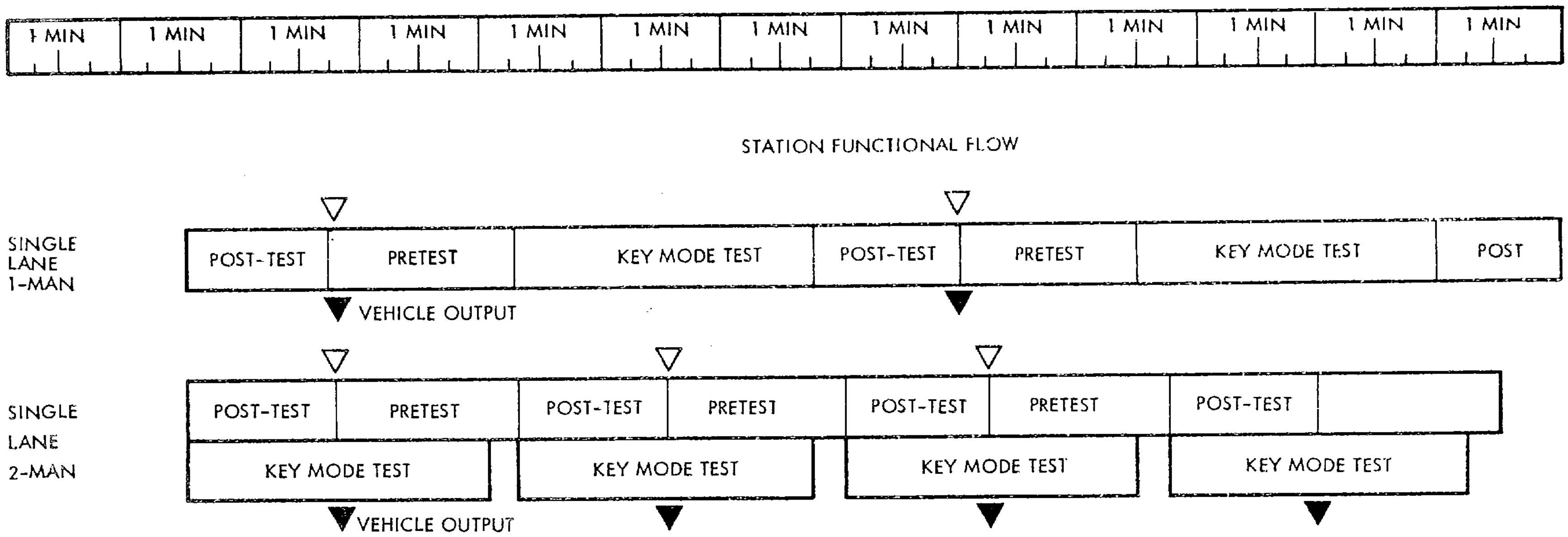
Figure 4-10. IDLE MODE TEST STATION FUNCTIONAL FLOW



FUNCTIONAL FLOW SUMMARY TABLE

	SINGLE LANE		DOUBLE LANE	
VEHICLES PER HOUR	11.4	21.8	33.2	43.6
AVG TIME PER VEHICLE	5.25	2.75	1.8	1.37
SLACK TIME PER HR	0	5.5	0	11
TEST CREW SIZE	1	2	3	4

PRETEST TIME	1.5
TEST TIME	2.5
POST-TEST TIME (PASS)	.5
POST-TEST TIME (FAIL)	2.0
POST-TEST TIME (AVERAGE)	1.25

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Figure 4-11. KEY-MODE SINGLE LANE STATION FUNCTIONAL FLOW

4.4.2 Idle Inspection Station Flow Analysis

Idle facility functional flow is described in Figure 4-10. Single lane functional flows with one and two man test crews were studied. Further hardware cross-utilization is not seen as practical and double lane station requirements are essentially twice the single lane personnel and equipment requirement. Maximum testing capability of a single man, single lane facility is 17 vehicles per hour. Output capability increases proportionally and a double lane station with four men has a capability of 68 vehicles per hour.

4.4.3 Key-Mode Station Flow Analysis

Key-Mode station functional flow is described in Figure 4-11. Single lane functional flows with one- and two-man crews are studied. Further hardware cross-utilization is not practical and double lane test equipment requirements are essentially twice that of single lane. Maximum testing capability for single lane two-man operation is 21 vehicles per hour; when expanded to double lane, a 43-vehicle per hour throughput rate can be realized.

4.4.4 Diagnostic Inspection Station Flow Analysis

Diagnostic inspection station functional flow analysis is conducted for various crew sizes. Full utilization of the equipment in a single lane station occurs with a four-man crew when average test times from the Test and Diagnostic function analyses are used and 50 percent of the vehicles fail the initial inspection. Multiple lane stations require a complete equipment complement for inspection and diagnostic equipment complement to supply each diagnostician. A complete double lane configuration includes the equipment and personnel complement of two single lane stations and can process twice as many cars. No extra benefit in personnel or inspection/diagnostic equipment can be realized from their cross-utilization between lanes in multiple lane stations.

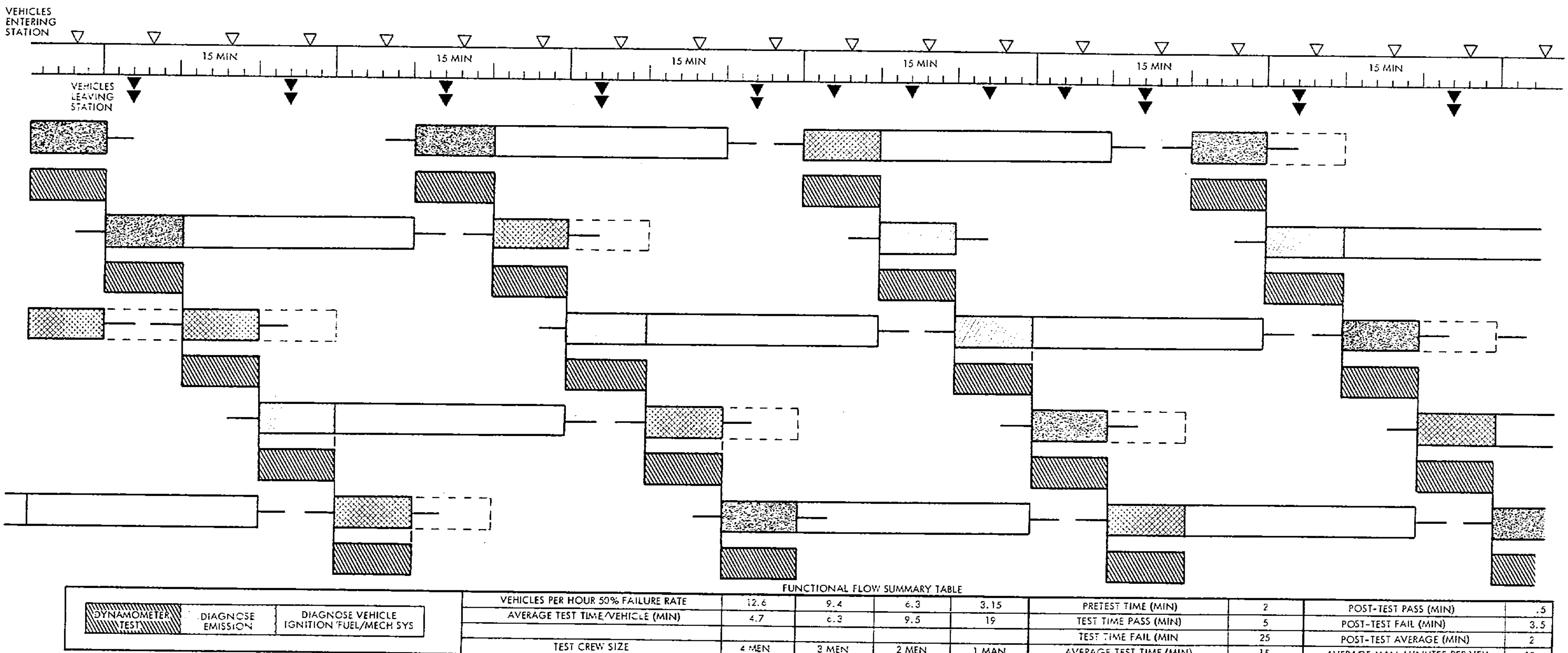
The station capability in vehicles/hour/lane, assuming average test times and 50 percent vehicle inspection failure rate, is 12.6 for a four-man station, 9.4 for a three-man station, 6.3 for a two-man station and 3.2 for a one-man station. Average test time is 15 minutes. The station functional flow analysis for a four-man crew is shown in Figure 4-12.

4.4.5 Station Flow Analysis for Inspection Tests Conducted at Existing Repair Facilities

The following paragraphs outline the inspection regime time requirements if the inspections were conducted at an existing repair facility. Figure 4-13 depicts the sequence of operation from the time the car enters the inspection system until it leaves the system passing the emission standard.

The times were estimated for one technician performing the inspection test. Automatic data readout and 75/25 percent pass/fail rates were used as assumptions to establish the time estimates. The inspection regime requires the following three subtasks to complete the tests.

a. Pretest
b. Inspection
c. Post-test.



FUNCTIONAL FLOW SUMMARY TABLE

VEHICLES PER HOUR 50% FAILURE RATE	12.6	9.4	6.3	3.15
AVERAGE TEST TIME/VEHICLE (MIN)	4.7	6.3	9.5	19
TEST CREW SIZE	4 MEN	3 MEN	2 MEN	1 MAN

PRETEST TIME (MIN)	2
TEST TIME PASS (MIN)	5
TEST TIME FAIL (MIN	25
AVERAGE TEST TIME (MIN)	15

POST-TEST PASS (MIN)	.5
POST-TEST FAIL (MIN)	3.5
POST-TEST AVERAGE (MIN)	2
AVERAGE MAN-MINUTES PER VEH	19

Figure 4-12. DIAGNOSTIC SINGLE LANE TEST STATION FUNCTIONAL FLOW

Table 4-2. TEST TIMES AND SINGLE LANE CAPABILITY

	Certificate of Compliance	Idle	Key-Mode	Diagnostic
Pretest Time (minutes)	1.5	1.5	1.5	2.0
Test Time (Average*) (minutes)	11.0	1.5	2.5	15.0
Passing Vehicles (minutes)	11.0	0.25	2.5	5.0
Failing Vehicles (minutes)	11.0	1.25	2.5	25.0
Post-Time (Average*) (minutes)	2.0	0.75	1.25	2.0
Passing Vehicles (minutes)	0.5	0.25	0.5	0.5
Failing Vehicles (minutes)	3.5	1.25	2.0	3.5
Total Inspection Time (minutes) per Vehicle (Average*)	13.5	3.5	4.9	13.3
Vehicle Throughput (Vehicles per Hour)*	4.0	34.0	31.8	16.0
Test Crew Size (Maximum Equipment Utilization)	1.0	2.0	2.0	4.0
Vehicles per Man-Hour*	4.0	17.0	11.4	4.0

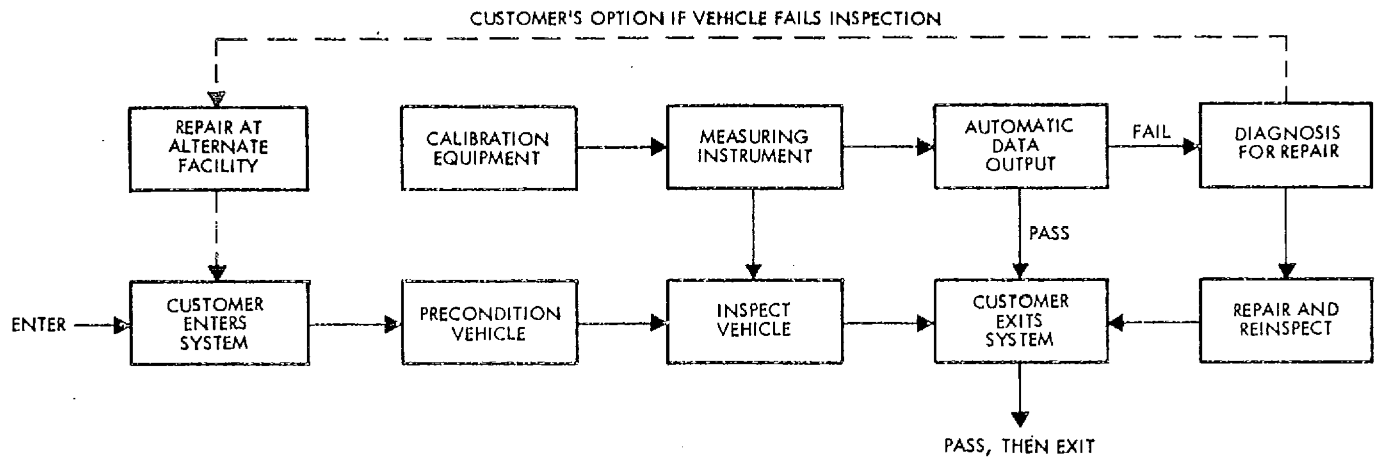
*Assumes 25 percent of vehicles fail inspection

Total times for each inspection regime were estimated and are listed in Figure 4-13. With a 75/25 percent pass/fail rate, the inspection times were weighted, to establish a mean inspection time. Estimated "real life" inspection times for one technician conducting the tests are as follows:

Test	Estimated Real Life Time Minutes*	Maximum Cars Inspected per Day
Certificate of Compliance	45	10
Idle	30	16
Key-Mode	30	16
Diagnostic	45	10

*Based on a pass/fail rate of 75/25 percent in existing repair facilities.

4.4.5.1 Pretest Operations - Pretest operation involves positioning the vehicle at the test location in the existing repair facility. If the Key-Mode or Diagnostic regimes are applicable, then the vehicle would be positioned on the dynamometer. Inspection of the car's exhaust system would be conducted by momentarily blocking



	C OF C	IDLE	KEY MODE	DIAGNOSTIC
PRETEST				
POSITION VEHICLE	1.0	1.0	1.0	1.0
INSPECT EXH. SYSTEM	1.0	1.0	1.0	1.0
PRECONDITION VEHICLE	0	1.0	0	0
INSPECTION				
CALIBRATION	1.0	1.0	1.0	1.0
INSTRUMENT HOOKUP	1.5	0.5	1.5(1)	1.5
CONDUCT INSPECTION	19.0	1.0	5.0	21.0
REMOVE INSTRUMENTS	1.5	0.5	1.5	1.5
POST TEST				
PASS - COMPL REPORT	5.0	5.0	7.0	10.0
FAIL - DIAGNOSIS (2)	15.0	15.0	15.0	15.0
REPAIR	NA(4)	NA	NA	NA
REINSPECT	11.0	6.0	11.0	16.0

TOTAL INSPECTION TIME, MINUTES (1 MAN) EST.

TEST	PASS	FAIL	WEIGHTED	(3)REAL
C OF C	30	51	35	45
IDLE	11	27	15	30
KM	18	37	22	30
DIAG	37	58	42	45

(1) DISCUSS WITH CUSTOMER

(2) INCLUDES SCOPE HOOKUP (CLAYTON'S LATEST RECOMMENDATION)

(3) 25% FAIL, 75% PASS

(4) NOT APPLICABLE TO INSPECTION TIMES

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Figure 4-13. INSPECTION TESTS CONDUCTED AT EXISTING REPAIR FACILITIES the tailpipe of an idling engine and listening for leaking exhaust gases. If the car had a leaking exhaust, repairs would be required prior to inspection to avoid sample dilution.

Preconditioning the engine would be required on the Idle test regime only. The preconditioning should be conducted just prior to the Idle emission test with a warmed up engine. The preconditioning would include operating the engine at 2500 rpm in neutral for 1 minute.

For the Certificate of Compliance, Key-Mode, and Diagnostic test regimes, engine preconditioning is accomplished during the test procedure. As an example, the Key-Mode high cruise test condition would provide engine preconditioning prior to the emission measurements.

4.4.5.2 Inspection Operations - The applicable vehicle emission inspection would be conducted as described in paragraph 4.1. The inspection would include the instrument calibration and hooking it up to the car. The measured emission data would be recorded during the inspection test for processing as outlined in Section 3. Ancillary data, such as owner and make/model identification, would be entered in for processing.

4.4.5.3 Post-Test Operations - The compliance report would be automatically printed out as described in Section 3. The repair technician would then present the results to the owner. If the car fails the inspection, the repair technician would conduct the applicable diagnosis to determine the cause of failure and then provide the customer with a written price estimate of the required repairs. At this point the customer would have the option to pay for the inspection, or have it repaired elsewhere and then reinspected. The other option would be to agree to have the car repaired and reinspected. However, in either case, the customer would be obligated to meet the State's time requirements for passing the emission inspection.

4.4.5.4 Time Requirements - The inspection time requirements for one technician are listed in Figure 4-13. Individual times for each task are listed for all four inspection regimes. Total inspection times are listed for both passing and failing vehicles. With a pass/fail rate of 75/25 percent, the total weighted mean inspection times can be calculated as follows:

0.75 (inspection time passed vehicles) + 0.25 (inspection time failed vehicles).

Figure 4-13 also shows that the Idle inspection regime takes the least weighted time (15 minutes if the vehicle passes inspection) and the Diagnostic takes the longest weighted time (42 minutes for a passing vehicle).

Since the inspections are being conducted at a commercial repair facility, it would be reasonable to expand the time requirements to the next highest 15-minute interval. It must be recognized that one technician is conducting the applicable inspection test, and one must allow for start-up and shutdown time.

Estimated "real life" times are presented in Figure 4-13. Note that the Key-Mode and Idle test regimes would take an estimated 30 minutes for each car. Diagnostic and Certificate of Compliance inspection tests take 45 minutes. These times would allow up to 16 Idle or Key-Mode tests per day for one technician. One technician could inspect approximately 10 cars per day on the Certificate of Compliance or Diagnostic tests. These times do not include time for repair which would be an additional charge to the customer.

4.5 FACILITIES

In determining the facility configuration and size, engineering analysis of the functions and assistance from industrial engineering personnel was required. A floor plan and artist's conception of the exterior for each double lane configuration was developed (Figures 4-14, 4-15, and 4-16). Each facility was designed with durable but attractive and inexpensive construction to provide the necessary enclosure for the equipments and personnel. Industrial engineering personnel recommended that the facilities be constructed of wood frame, 10-foot stucco and plasterboard walls, with 90-pound felt hot-mopped roofs. Two 10 by 10-foot aluminum overhead garage doors were provided for each inspection lane. The estimates included interior walls and doors for utility and office spaces, concrete slab floors with a 6-foot-deep concrete lined inspection pit. The inspection pit was provided with sump pump, access stairs, and covered with expanded metal grating. Fire suppression sprinklers, compressed air (110 psi) and electrical convenience outlets were provided throughout the working areas. Each facility had one restroom containing one toilet and one wash basin. The exterior yard was asphalt with painted aisles and parking stalls. Each dynamometer was provided with a concrete lined pit ready for installation. Each dynamometer and engine diagnosis stall was provided with a 2500 cfm exhaust recovery system using 6-inch flexible hose. The exhaust gases were routed through floor ducts and up side walls for discharge above the building roof. Each single or double lane diagnostic station was equipped with an additional restroom.

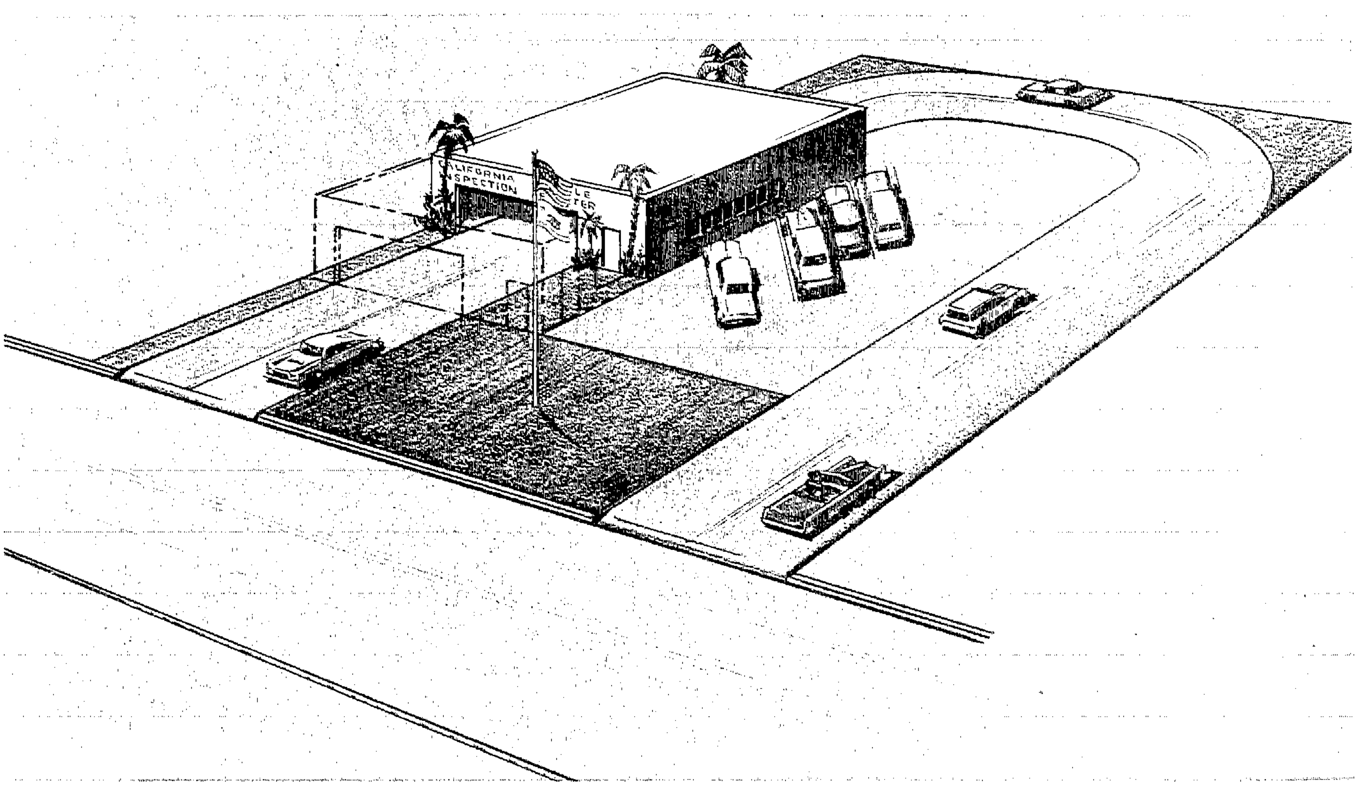


Figure 4-14. ARTIST'S CONCEPTION OF IDLE INSPECTION STATION

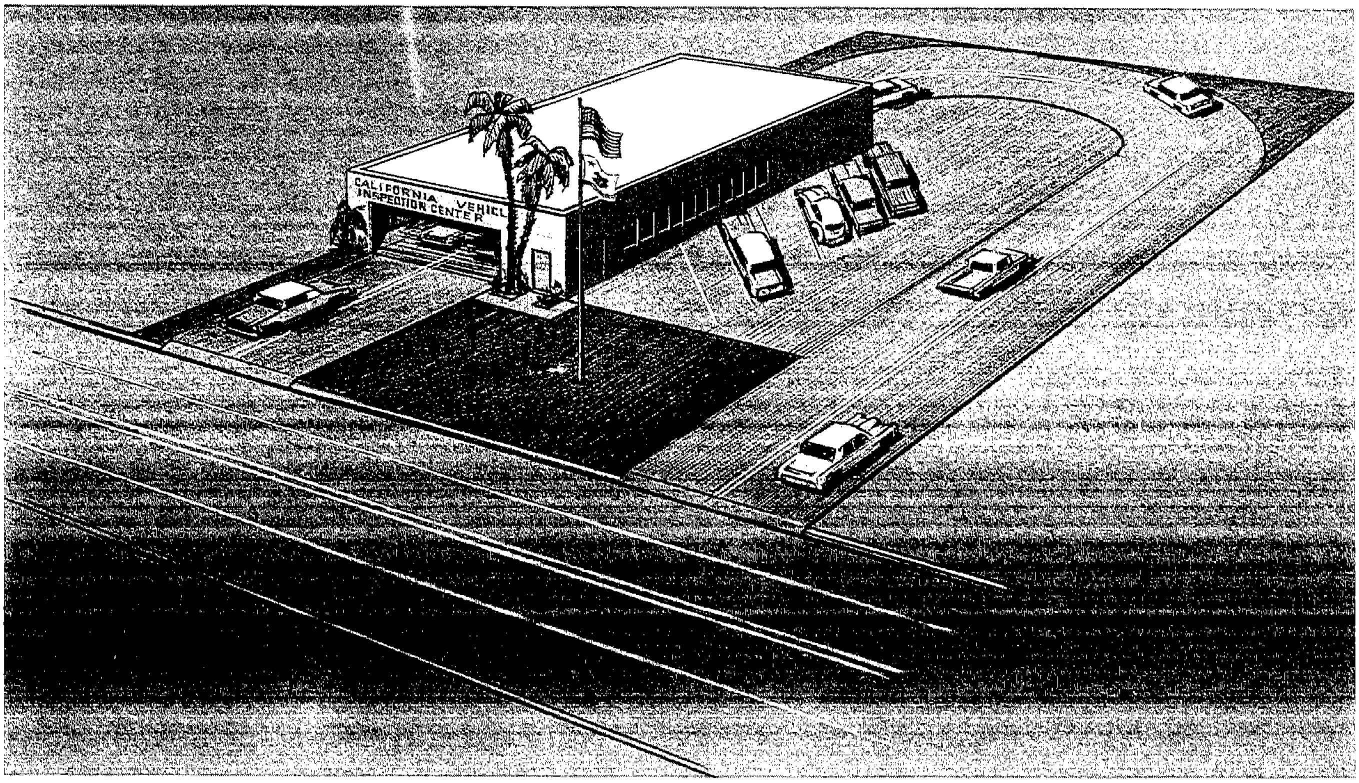


Figure 4-15. ARTIST'S CONCEPTION OF KEY-MODE INSPECTION STATION

4.5.1 Mobile Facilities

Each mobile inspection facility was equipped with the required equipments for a single lane of the respective regime. In addition, the mobile facility required a van of sufficient size to transport the inspection personnel, equipments and 110 vac power supply and where applicable, a dynamometer mounted on a trailer.

4.6 EQUIPMENT

Equipment and area requirements were identified for single and double lane station configurations of each test regime. Specific instrument requirements are identified in the instrumentation review of Section 3. Vehicle inspection test equipment requirements (Table 4-3), were developed for each regime. The instruments and other equipment were grouped in their generic groups and assigned to each regime's station configurations of from one to seven lanes. Seven lanes were arbitrarily chosen as the maximum station size. Driver waiting areas, utilities, and office spaces were designated. The test facility size requirements were generated by analysis (minimum size) and refined by industrial engineering personnel (recommended size). Two-lane station floor plans resulting from the analysis are shown in Figure 4-17 for two-lane configurations.

4.6.1 Equipment Types and Generic Groups

The equipment is described as inspection equipment, inspection support equipment, and administrative support equipment. The inspection equipment includes the following five groups: (1) Dynamometer system including dynamometer, controls, readouts,

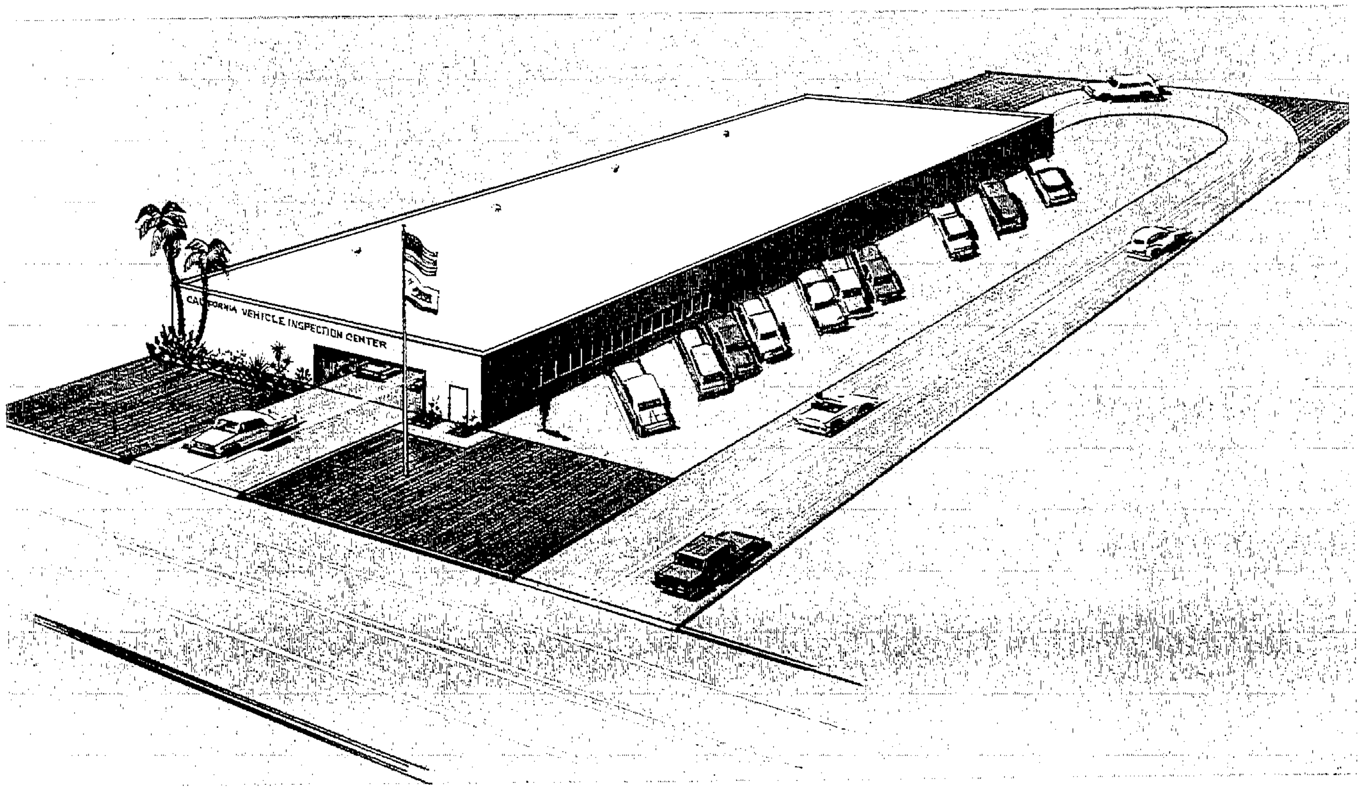


Figure 4-16. ARTIST'S CONCEPTION OF DIAGNOSTIC INSPECTION STATION

cooling fan, (2) exhaust emission inspection test system for HC, CO, NO, AND O_2 including the sample system and gas analyzers, (3) engine diagnostic equipment including scope, meters, probes, (4) exhaust emission analysis system for HC and CO for engine diagnosis and the Certificate of Compliance test, and (5) the data processor/recorder system.

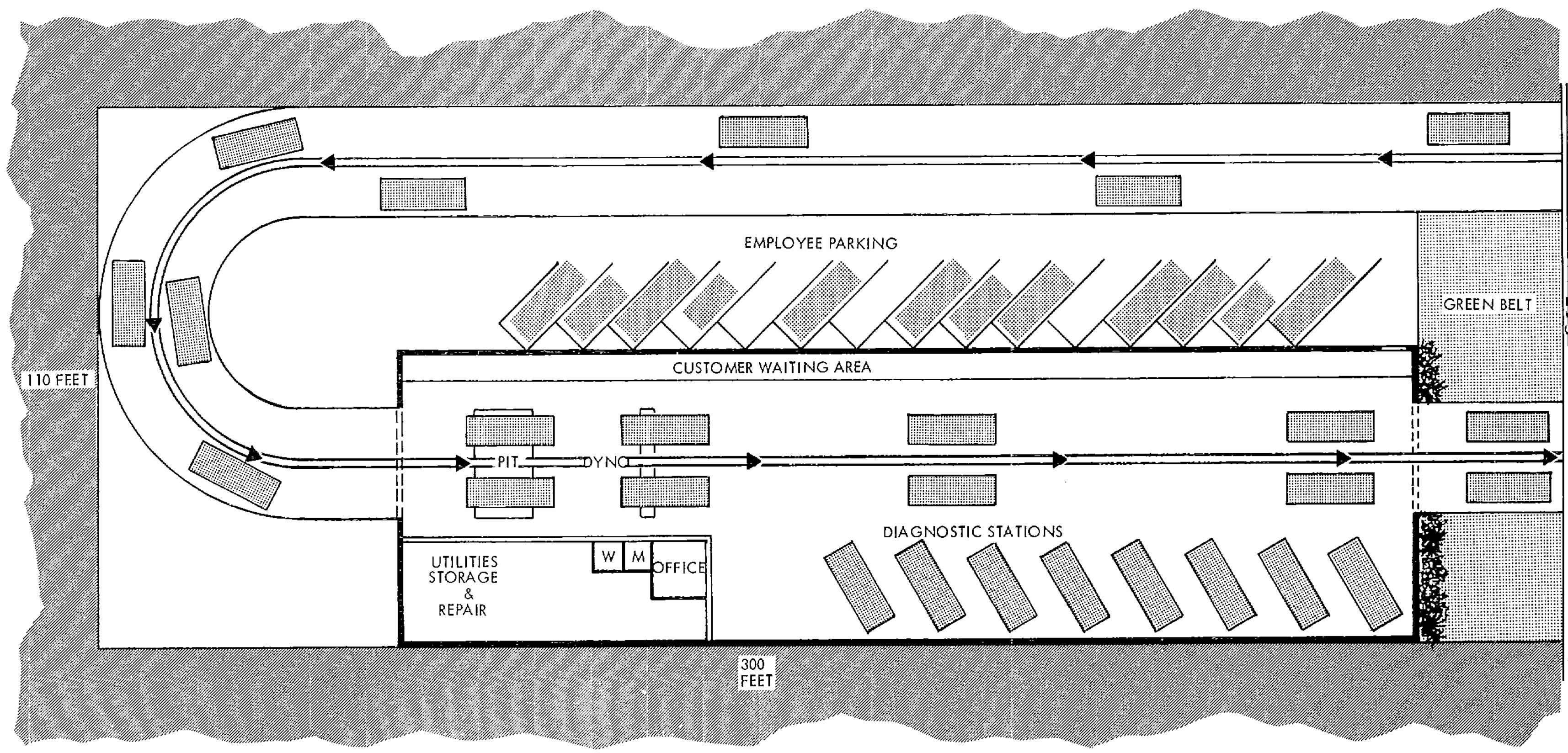
During the analysis, the exhaust emission inspection test system and the data processor/recorder functions were combined into a single instrument package. This package was assigned to each lane of all the test regimes except Certificate of Compliance which was assigned only the exhaust emission analysis system, numbered (4). This distinction was considered most realistic in terms of the level of emission measurement sophistication required. The HC, CO analyzers (4) have 5 percent accuracy; the HC, CO, NO analyzers (2) have 1 percent accuracy.

The inspection support equipment includes equipment and supplies required to calibrate and maintain the inspection equipment including expendable items such as sample probes, filters, and belts. The administrative support equipment includes the office equipment, fixtures, and public facilities required to maintain and operate the facility and conduct the necessary routine administrative functions. Administrative equipment is shown in Table 4-4.

Table 4-3. INSPECTION STATION EQUIPMENT AND LANE PERSONNEL REQUIREMENTS

Regime	Number of Units							
	Certificate of Compliance		Idle		Key-Mode		Diagnostic	
Number of Lanes	1	2	1	2	1	2	1	2
Facility Area (Square Feet)	1370	2040	1370	2040	2040	3060	10,100	12,600
Property Area (Square Feet)								
Inspection Equipment								
1. Chassis Dynamometer	-	-	-	-	1	2	1	2
2. Inspection/Test System	-	-	1	2	1	2	1	2
3. Engine Diagnostic System	1	2	-	-	-	-	4	7
4. HC, CO Diagnostic Analyzer	1	2	-	-	-	-	3	5
5. Data Recording System	-	-	1	2	1	2	1	2
Inspection Personnel* (Maximum Equipment Utilization)								
1. Inspection/Test Technician III	1	2	-	-	-	-	2	2
2. Inspection/Test Technician II	-	-	2	2	1	2	1	2
3. Inspection/Test Technician I	-	-	-	2	1	2	1	4
Total Personnel Requirement	1	2	2	4	2	4	4	8

*Skill levels as outlined in Table 4-5.



DIAGNOSTIC TYPE

Figure 4-17. TWO-LANE STATION FLOOR PLANS (Sheet 1 of 3)

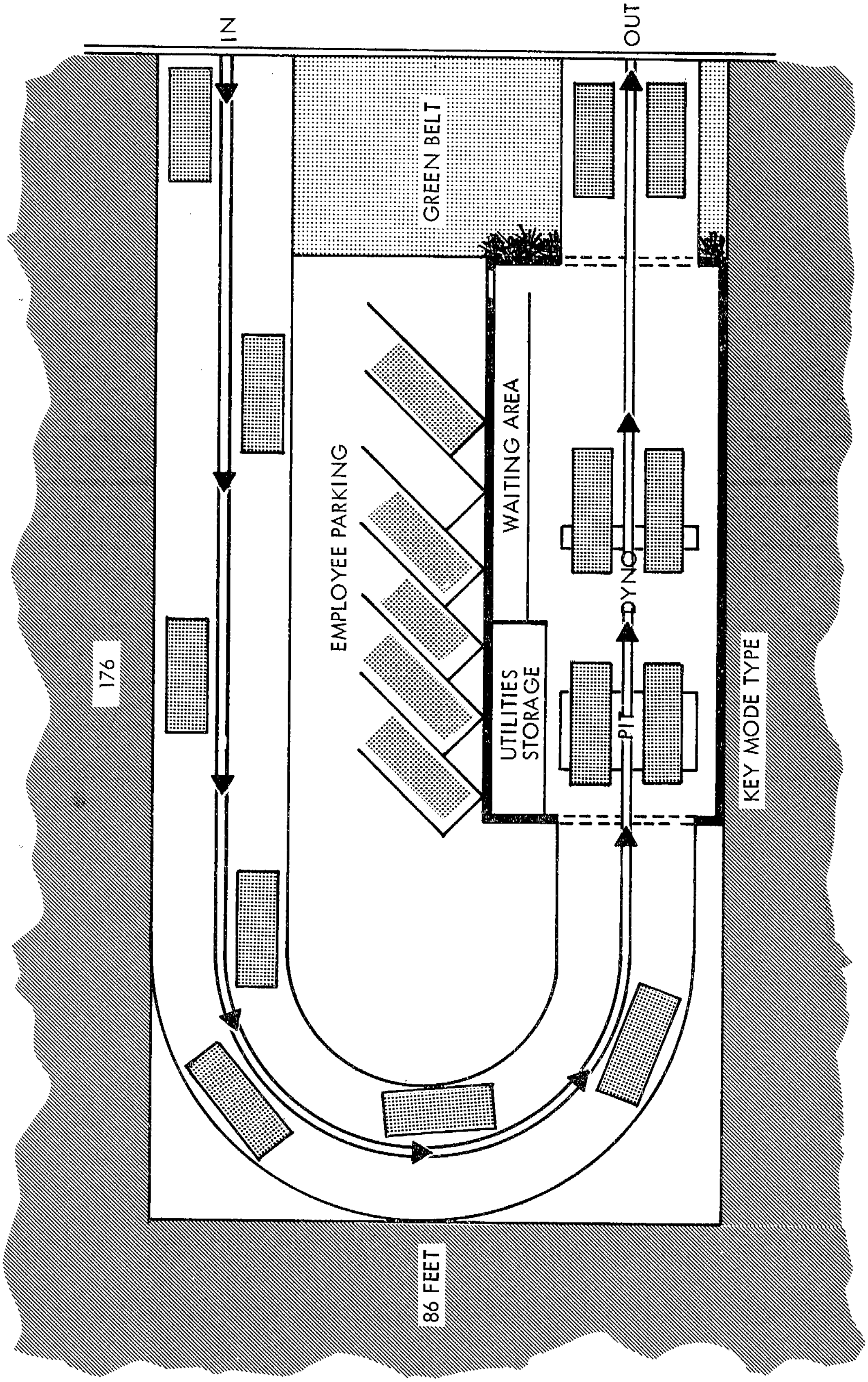


Figure 4-17. TWO-LANE STATION FLOOR PLANS (Sheet 2 of 3)

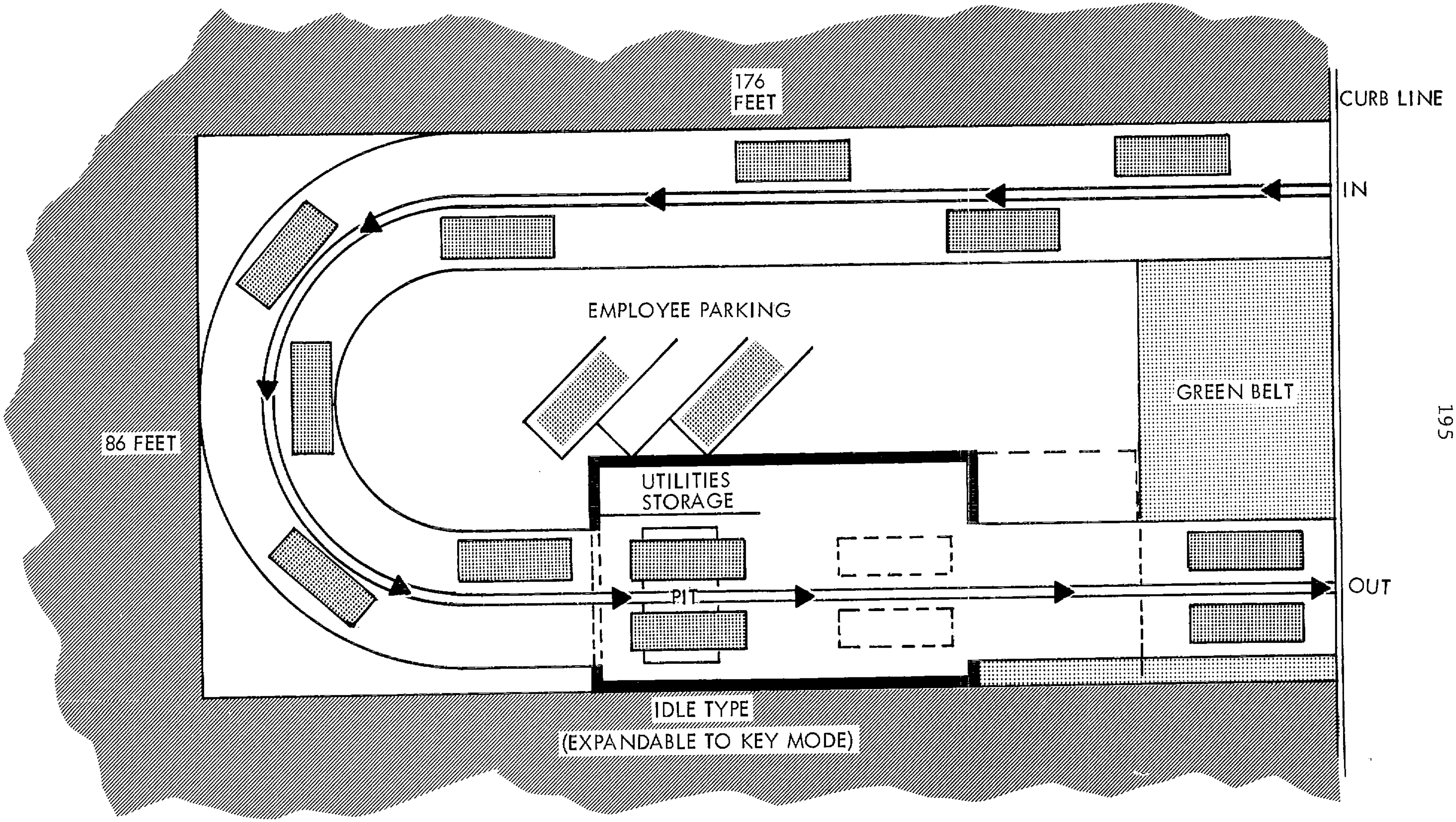


Figure 4-17. TWO-LANE STATION FLOOR PLANS (Sheet 3 of 3)

Table 4-4. STATION ADMINISTRATIVE SUPPORT COSTS

	Station Type (Number of Lanes)		Number of Units							
			Mobile	1	2	3	4	5	6	7
Certificate of Compliance	Administrative Personnel									
	Manager II	$7.05/hr	0	0	0	0	0	0	0	0
	Manager I	$6.30/hr	0	0	0	0	0	0	1	1
	Clerk	$3.82/hr	0	0	0	0	1	1	1	1
	Administrative Equipment									
	Office Equipment Set	$700	0	1	1	1	2	2	3	3
	Public Equipment Set	$150	0	1	2	3	4	5	6	7
Idle	Administrative Personnel									
	Manager II	$7.05/hr	0	0	0	0	0	0	1	1
	Manager I	$6.30/hr	0	0	0	0	1	1	0	0
	Clerk	$3.82/hr	0	0	0	1	0	1	1	1
	Administrative Equipment									
	Office Equipment Set	$700	0	1	2	3	4	4	4	4
	Public Equipment Set	$150	0	1	2	3	4	5	6	7
Key-Mode	Administrative Personnel									
	Manager II	$7.05/hr	0	0	0	0	0	0	1	1
	Manager I	$6.30/hr	0	0	0	0	1	1	0	0
	Clerk	$3.82/hr	0	0	0	1	0	1	1	1
	Administrative Equipment									
	Office Equipment Set	$700	0	1	2	2	2	3	3	3
	Public Equipment Set	$150	0	1	2	3	4	5	6	7
Diagnostic	Administrative Personnel									
	Manager II	$7.05/hr	0	0	0	0	0	1	1	1
	Manager I	$6.30/hr	0	0	1	1	1	0	1	1
	Clerk	$3.82/hr	1	1	1	1	2	2	2	2
	Administrative Equipment									
	Office Equipment Set	$700	0	1	2	3	4	4	4	4
	Public Equipment Set	$150	0	1	2	3	4	5	6	7

Office Equipment Set: 1 desk, 2 chairs, 1 typewriter, 1 storage cabinet, 1 file cabinet, 1 card file

Public Equipment Set: 5 chairs, 1 table

4.7 PERSONNEL REQUIREMENTS

The following paragraphs outline the personnel requirements for operating the emission inspection station. The required staff and skill levels are defined. The training requirements including the curriculum, facilities, and instructor training conclude the discussion. Summaries and recommendations are presented and are supported by additional text, tables, and figures. The following statements summarize the manpower requirements to staff and operate an emission inspection station:

a. Skill Levels - Inspection station personnel skill levels are based on auto technician skill levels currently available from the industry. Level III requires 5 years experience and some formal education in the auto tuneup and diagnostic field. Level II requires 3 years tuneup and diagnostic experience with some formal education. Level III requires some tuneup experience and vocational auto or trade school education.

b. Inspection Station Staff - The Diagnostic inspection regime requires the highest skill levels to operate the lanes. Two level III inspectors and one each of levels II and I inspectors will be required to operate one Diagnostic lane. The Key-Mode and Idle inspection regimes require one inspector at level II and one at level I to operate one inspection lane. The Certificate of Compliance regime requires one man at level I to operate one lane.

c. Data Processing - The inspector in charge of the inspection station must issue pass or fail certificates. A written diagnosis outlining the emission problems would be a major contribution to any inspection regime.

d. Equipment Maintenance - Inspection station personnel will be required to conduct instrument calibrations, routine maintenance, and repair minor mechanical failures. Equipment manufacturers or program management will service equipment when internal or major repairs are required.

e. Training Requirements - To assure the successful implementation of the selected inspection regime, effective training for station inspectors is obviously mandatory. Some recommendations are in order for a manpower development program which can be offered to inspection personnel and instructors. Existing public education facilities can be utilized to implement statewide inspector training programs.

f. Curriculum - The recommended curriculum is quite similar for all four inspection regimes. It features classroom instruction, laboratory demonstrations, and on-the-job training (OJT). The distribution of training hours is shown in Figure 4-18. Laboratory demonstrations and OJT account for 59 to 76 percent of the total training effort for all test regimes. The Diagnostic training effort is the longest at 174 hours and the Idle test is the shortest at 87 hours. Both the Key-Mode and Diagnostic regimes require dynamometer training.

g. Training Facilities - The training program could be implemented into California's existing public education facilities. School laboratories could be equipped with the applicable inspection station instrument packages. Dynamometer facilities with as many as four dynamometers are currently available through private industry. On-the-job training would be conducted at the inspection station.

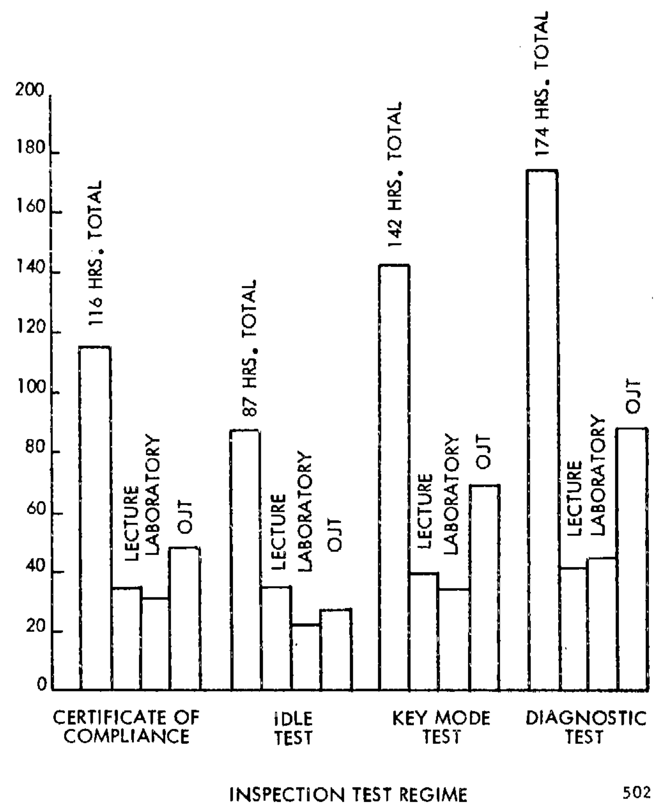


Figure 4-18. TRAINING REQUIREMENT DISTRIBUTION FOR INSPECTION STATION PERSONNEL

h. Training Instructors - Qualified and credentialed teachers would be selected as training instructors provided that they could meet the level III skill requirements. All instructors would be required to attend the inspection training class prior to their teaching the class. Initial training programs for instructors can be conducted by personnel already involved in the vehicle emission control and emission measurement training programs.

4.7.1 Inspection Personnel

To assure the success of any vehicle emission inspection test, it is imperative that the State select and train competent inspectors to operate the stations. Since the inspection involves vehicle emission measurements, the inspector should have a strong automotive background as well as a good mechanical aptitude. He must thoroughly understand vehicle operation for the various test modes, and must be cognizant of emission control system technology. In addition, he should be able to confront the motorist with a pleasant attitude regardless of the inspection test results. Inspection personnel requirements are outlined in terms of skill levels, the inspection station staff, data processing procedures, and equipment maintenance.

4.7.1.1 Skill Levels - The skill levels of the inspection personnel are divided into three categories:

Level III - The level III man is the chief inspector in a lane. He should have extensive experience in engine tuneup and repair, utilizing ignition analyzer scopes and air-fuel ratio meters as diagnostic tools. He should be a high school graduate, and be able to meet the public to discuss inspection test results and vehicle emission problems.

Level II - This inspector is responsible to the chief inspector. He should have tuneup experience with some time using the scope and air-fuel ratio meters. He should be a high school graduate and have the potential to meet the public.

Level I - This inspector is responsible to the chief inspector. He should have some tuneup experience and vocational auto or trade school training.

Table 4-5 lists the skill level requirements in more detail. The skill levels were based on auto repair technical skill levels that are currently available from the industry. Table 4-5 also could be used as a job description for selecting qualified personnel when the inspection system is implemented. Skill required specifically in the vehicle exhaust analysis program (e.g., those relating to instrument operation) will be added to these during the training program.

As an inspector advances within his respective skill levels, he could upgrade his formal education to help fulfill the requirements for advancing to the next skill level.

4.7.1.2 Inspection Station Staff - Table 4-6 lists the staff requirements to operate and maintain an emission inspection station. The number of required personnel is listed for both one and 2 lane stations by the required skill levels. The staff for each test regime was based on an optimum throughput of vehicles as described in paragraph 4.4. Table 4-6 shows that the Diagnostic regime would require the highest skill level and four staff members for a one lane station. The Idle and Key-Mode tests require two staff members at the medium and low skill level to operate a one lane station. The Certificate of Compliance test requires one person at the highest skill level to operate a one lane station.

4.7.1.3 Data Processing - The inspection personnel would be required to document vehicle emission inspections. Compliance certificates would be designed for the applicable test regime as discussed in Section 3. The inspector would present the pass or fail certificates to the motorist. These could include a written diagnosis of the problems causing high emissions. A policy of "being in the diagnostic business" or just issuing pass-fail test results must be clearly defined before data processing procedures are completed.

4.7.1.4 Equipment Maintenance - The inspection station personnel would be required to maintain the test equipment. It is recommended that system maintenance be performed at the station. This would include routine calibration and sample line repair and cleaning on the HC, CO, and NO meters. Plug-in modules in the instrumentation system could be replaced. Instrument repairs would be conducted by the instrument manufacturer or program management office.

Table 4-5. SKILL LEVELS, INSPECTION PERSONNEL

Inspection Technician Level	Salary Range $ Per Year	Technical Experience	Formal Education and License Requirements	Personality
III	12 - 15,000	5 full years as a journeyman tuneup technician. Must have repair experience and technical expertise in engine tuneup diagnosis utilizing ignition analyzer scope, air-fuel ratio meter and the chassis dynamometer (dynamometer training acceptable as an equivalent).	High school with vocational auto and/or trade school. College level training desirable. Must have valid California Class A Smog License.	Must be able to meet public to discuss pass-fail test results and vehicle emission problems.
II	9 - 11,000	3 years as a journeyman tuneup repair technician and some experience in the use of the ignition analyzer scope, air-fuel ratio meter as a diagnostic tool.	High school or equivalent. Vocational auto or trade school training desirable. Must have valid California Class A Smog License.	Must be able to meet public.
I	7 - 8,000	1 year as a tuneup technician with experience in removing and replacing ignition and carburetor components.	Vocational auto or trade school training desirable.	Must be able to meet public.

Table 4-6. INSPECTION STATION STAFF REQUIREMENTS

Inspection Technician Level*	Static Inspection				Dynamic Inspection			
	Cert of Compl		Idle Test		Key-Mode		Diagnostic	
	1 Lane	2 Lane	1 Lane	2 Lane	1 Lane	2 Lane	1 Lane	2 Lane
III	1	2	-	-	-	-	2	2
II	-	-	1	2	1	2	1	2
I	-	-	1	2	1	2	1	4
Total	1	2	2	4	2	4	4	8

*Skill levels outlined in Table 4-1.

Maintenance of the ignition analyzer scopes would include calibration (as required on some scopes) and maintenance of hookup probes. Internal maintenance and electronic malfunction would be conducted by the scope manufacturer.

Dynamometers would require routine lubrication and minor repairs such as broken wires at control switches. Control system repair, dynamometer roll bearings replacement, and calibration would be conducted by the dynamometer manufacturer.

The data processing equipment malfunctions could be serviced with plug-in replacement PC boards. Major repair problems would be serviced by the equipment supplier.

4.7.2 Training Requirements

As the inspection regimes are implemented, the candidate inspectors at any skill level will be deficient on certain essential skills. Most will not have a good technical background in the fundamentals of emission measurements and the operation of current and future emission control systems. However, they should have knowledge of good tuneup techniques from a performance standpoint. The training program will provide all inspectors (at all levels) with a working knowledge of emission measurements and the basics of emission control system operation.

4.7.2.1 Curriculum - The curriculum is designed to provide the student with a "real life" knowledge of emission measurements and emission control systems. The course features classroom, laboratory, and OJT in the following categories:

a. Automotive Pollution Sources
b. Carburetor Operation Review
c. Ignition Operation Review
d. Ignition Analyzer Scope Fundamentals
e. Crankcase Emission Control Systems
f. Air Injection Exhaust Control Systems
g. Engine Modification Exhaust Control Systems
h. Evaporative Emission Control Systems
i. Certification Procedures
j. Emission Measurements
k. Dynamometer Operation (if applicable).

A detailed curriculum is shown in Table 4-7. The lecture content is listed along with laboratory problems. These problems are typical real life malfunctions that cause high emissions. It must be recognized that the course content will be tailored to fit the selected inspection test regime. It is recommended that the classes be held during daytime hours in two sessions. Generally, the morning session will be the lecture portion and the afternoon will be the laboratory application portion.

Table 4-7. SAMPLE COURSE CURRICULUM AUTO EMISSION INSPECTOR TRAINING

Lesson Number	Lecture Content	Laboratory Problems
	Carburetor and Ignition Review	
1	Automobile Pollution Sources	
	• Blowby, exhaust, evaporative emissions	None
2	Carburetor Review	
	• Basic circuits • Air-fuel ratio vs CO	Idle and main circuit Malfunction diagnosis
3	Ignition Review	
	• Mechanical operation • Electrical operation (scope pattern)	Scope pattern displays
4	Scope Fundamentals	
	• Hookup and operation • Total advance • Equipment maintenance	Fouled plug, open plug wires Vacuum and mechanical advance Scope hookup wiring
	Emission Control Systems	
5	Crankcase Emission Control System	
	• Type 1 (open) • Type 2 • Type 3 (sealed) • Type 4 (closed)	Plugged PCV valve Crankcase vacuum measurements Oil pullover Blowby and PCV valve flow
6	Air Injection Systems	Pump flow and relief pressure
	• Antibackfire protection	"Gulp" and diverter malfunction
	• Carburetor modifications	Idle mixture adjustment, pump disconnected
	• Ignition modifications	Retarded timing at idle

Table 4-7. SAMPLE COURSE CURRICULUM AUTO EMISSION INSPECTOR TRAINING (Continued)

Lesson Number	Lecture Content	Laboratory Problems
7	Engine Modification Systems	
	• Carburetor modifications	Idle mixture limiters
	• Ignition modifications	Solenoid and vacuum retard at idle. Dual vacuum advance
	• NO_x control	Vacuum retard during low speed operation
	• Accessory devices	Throttle positioner, heated air inlet
8	Evaporative Control Systems	
	• Charcoal storage	Pressure-vacuum relief
	• Crankcase storage	Fuel vapor separator
9	Certification Procedures	
	• Application of approved devices	
	• Certificate of Compliance	
	<u>Emission Measurements</u>	
10	Test Regime Procedures	
	• Emission measurements	HC and CO meter operation
	• Pass-fail criteria	Failed vehicle diagnosis
	• Equipment maintenance	Cleaning instruments
	<u>Chassis Dynamometers</u>	
11	Dynamometer Operation	
	• Vehicle loads	Vehicle operation
	• Diagnostic cycles	Key-mode and/or diagnostic
	• Equipment maintenance	Lubrication, braking

The laboratory session will be devoted to demonstrations and application of material covered during the lecture. Demonstrations will be conducted by the instructor to familiarize the inspector students with typical diagnosis problems and adjustments. Problem solving with a performance evaluation of each student will conclude each laboratory session.

An OJT period under the direction of the chief inspector will follow the formal training session at the inspection station. This will provide the inspector student with effective "hands on training." Past experience has shown that the combination of lecture, laboratory and OJT instruction to be the best approach for complete training. The training would end with the certification of the inspector.

Table 4-8 lists the number of training hours required for each inspection regime. The table shows the total training hours for the class, laboratory and OJT portions. It is recommended that the morning (lecture) and afternoon (laboratory) sessions be no longer than 3 hours each. The rationale for this is that a student will lose interest if formal training sessions are longer than 3 hours. The OJT portion would be normal 8-hour working days.

Table 4-8. TRAINING TIME REQUIREMENTS, HOURS INSPECTION PERSONNEL

Training Category	Certificate of Compliance	Idle	Key-Mode	Diagnostic
Classroom Lecture				
• Ignition and Carburetor Review	12	12	12	12
• Emission Control Systems	12	12	12	12
• Emission Measurements	9	9	9	9
• Chassis Dynamometer	0	0	3	6
• Evaluation, Written	3	3	3	3
Total Classroom Instruction	36	36	39	42
Laboratory Demonstrations				
• Ignition Analyzer (Scope)	3	0	0	3
• Emission Control Systems	6	0	0	6
• Emission Measurements	6	6	6	6
• Chassis Dynamometer	0	0	6	6
• Evaluation, Performance	8	8	8	8
Equipment Maintenance				
• Repair at Technician Level	6	6	12	12
• Evaluation, Performance	3	3	3	3
Total Lab Instruction	32	23	35	44
On-the-Job Training (OJT)				
• "Hands On" Training	40	20	60	80
• Inspector Certification, Performance	8	8	8	8
Total OJT	48	28	68	88
Total Formal Training and OJT	116	87	142	174

Several text books are available for emission control system operation and emission measurements. Two of the better texts which are recommended are as follows:

a. Fundamentals of all emission control systems

 <u>Engine Emission Control Systems</u>
 National Service Department
 Autolite Ford Parts
 Box 3000, Lavonia, Michigan 48151

b. Emission measurements and automotive tuneup diagnosis

 <u>Automotive Evaluation and Emission Testing</u>
 Joe DeGiorgio 500 Automotive Evaluation Center
 500 East Wardlow
 Long Beach, California 90807

The first text is currently being used in vehicle emission control training classes and provides excellent fundamental operation of emission systems on all vehicles. The second text provides excellent performance tuneup diagnosis, low emission tuneup techniques, and emission measurement techniques for the auto repair technician. The text material will also be supplemented with classroom handouts tailored for a particular lesson plan.

Lesson plans will be formally prepared for each of the classes shown in the sample curriculum. All lesson plans will be designed to combine the standard presentation techniques of lecture and manipulative classes. Many of the lesson plans are currently being used in auto smog control training classes. A sample lesson plan of carburetor operation review is shown in Table 4-9, which includes a 3-hour lecture (morning session) and a 3-hour manipulative laboratory in the afternoon. In the lecture portion, bulletins on carburetor operation will be utilized along with the lecture slides. The laboratory portion features a demonstration of the CO and HC meter calibration and operation. The techniques of carburetor circuit diagnosis and idle mixture adjustment would be demonstrated at this time. Each student will then learn the technique of idle mixture and speed adjustment in accordance with vehicle specifications for lowest exhaust emissions and smooth idle performance. The laboratory portion will conclude with a performance evaluation of each student.

The inspector student's technical growth must be evaluated on a continuing basis. Both written and performance examinations will be used as a training aid for each class. This approach will provide a reasonable indication of the student's ability to grasp emission measurements and control system fundamentals. A sample carburetor performance evaluation sheet is presented in Figure 4-19. The student's ability to pass the performance evaluation will be based on correctly completing at least 80 percent of the listed steps shown in Figure 4-19. In the event the student does not satisfactorily pass the performance evaluation, he will receive further instruction in the following laboratory session and repeat the test.

4.7.2.2 <u>Training Facilities</u> - The physical configuration for the training facilities will depend primarily on the selected inspection mode. It is recommended that State public education classrooms be utilized in the lecture content of the course. Lecture classes would be limited to 30 students. Portable test equipment would be used as teaching aids where applicable.

Table 4-9. SAMPLE LESSON PLAN CARBURETOR OPERATION REVIEW

1. Objective and Scope

    1.1 Review carburetor operation
    1.2 Establish air-fuel ratio and CO relationship
    1.3 Acquaint auto technician with idle mixture adjustments and carburetor circuit diagnosis

2. Equipment Requirements

    2.1 Slides for lecture presentation
    2.2 Lecture material handouts
    2.3 Carbon monoxide, hydrocarbon meter and air-fuel ratio meter
    2.4 Tuneup hand tools
    2.5 Two cars (one with engine modification and one with air injection system)

3. Introduction

    3.1 Need for carburetor review
    3.2 Good tuneup yields good performance and low emissions
    3.3 Class content
        - Three hours lecture
        - Three hours laboratory including choke relief adjustments and circuit malfunction diagnosis

4. Lecture Presentation

    4.1 Basic Carburetor Circuits
        - Float
        - Idle low speed
        - Venturi principle
        - High speed (part load)
        - High speed (full load)
        - Accelerator pump
        - Choke system

    4.2 Adjustments and Diagnosis
        - A-F ratio vs CO
        - Idle adjustment
        - Effect of air injection pump
        - High speed circuit
        - Power valve

    4.3 Related Carburetor and Engine Problems
        - Fuel vaporization
        - Lean mixture
        - Valve overlap
        - Rough idle

Table 4-9. SAMPLE LESSON PLAN CARBURETOR OPERATION REVIEW (Continued)

5. Application (Laboratory)

   5.1 Demonstrate CO, HC meter, and air-fuel ratio meter

   - High speed circuit diagnosis
   - Idle circuit and idle adjustments
   - Effect of air injection pump
   - Choke relief

   5.2 Student Application

   - Train each student to adjust idle CO and speed for low emissions
   - Train each student to bench adjust choke relief

6. Evaluation

   6.1 Maladjust both demonstrator cars

   - Rich idle CO and low speed on air injection system car (black smoke)
   - Lean idle CO and high speed on engine modification car (lean misfire)

   6.2 Evaluate each technician's idle adjustment performance

Laboratory demonstrations also would be conducted at public education facilities. Vocational auto shop lab classes could be used for preliminary "hands on" training. The size of the class would accommodate 16 students and provide adequate individual training performance evaluations.

If dynamometers are required for inspection regime training, private industry in the Los Angeles area can provide classrooms with four dynamometers which would easily accommodate a class size of 16 student inspectors. All necessary equipment for engine diagnosis and emission measurements are currently available through these facilities.

On-the-job training can be conducted at the inspection station under close supervision of the chief inspector. Qualified instructors would certify the inspector students at the completion of the training session.

4.7.2.3 Instructors - Public education auto shop instructors who are currently teaching would be solicited to teach the inspection training program to student inspectors. Instructors would be selected on the basis of their California teaching credential plus meeting the level III skill requirements outlined in Table 4-5. All Instructors would be required to fulfill the inspector training requirements as outlined prior to teaching the course. Initial instructor training programs can be conducted by personnel already involved in the vehicle emission control training programs.

	PASS? YES	PASS? NO
1. VEHICLE AS RECEIVED BY STUDENT		
• CALIBRATE CARBURETOR (CO AND HC METER)		
• MEASURE AND RECORD IDLE SPEED HC AND CO		
• MEASURE AND RECORD MAIN CIRCUIT CO AND HC		
• WRITE CARBURETOR DIAGNOSIS (1)		
2. ADJUST CARBURETOR		
• REVIEW SPECIFICATIONS (2)		
• CALIBRATE CO AND HC METER		
• ADJUST IDLE SPEED		
• ADJUST IDLE MIXTURE (CO)		
• REPLACE AIR CLEANER		
• RECHECK IDLE ADJUSTMENT (CO)		
• RECORD FINAL IDLE MEXTURE (3)		
• RECORD FINAL IDLE SPEED (3)		

PASS EVALUATION ☐

REPEAT CLASS ☐

(1) CARBURETOR CIRCUIT DIAGNOSIS ______________________________

____

(2) IDLE SPECIFICATIONS - MAKE ______ YEAR ______ CID ______ CARB ____

SPEED ______ RPM CO ____% (OR A/F _____

(3) FINAL ADJUSTMENT SPEED __________ CO _____% HC ______ PPM

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Figure 4-19. SAMPLE CARBURETOR PERFORMANCE EVALUATION

4.8 NUMBER AND GEOGRAPHICAL DISTRIBUTION OF INSPECTION STATIONS

To provide cost estimates, it was necessary to determine the size and number of stations required for each inspection regime. Two analyses were conducted to derive this information. First, a station algorithm was developed which calculated the vehicle throughput (number of vehicles per day per lane) for each candidate inspection regime. This model permitted permutation of station operating variables such as effect of different failure rates, vehicle arrival times, and personnel complement. The output of this model (vehicles/day/lane) was then applied to a second algorithm which determined the number of lanes of each inspection regime required by localities. This information was used to determine the number and size of stations required by each inspection regime. This section documents the analyses and results of the station algorithms, the vehicle population centers, and finally the number of lanes for each air basin required for each test regime.

4.8.1 Inspection Station Simulation Model

A simulation model of the "real world" arrival of vehicles at an inspection station is used to determine the mean number of vehicles serviced per day. This throughput rate is then projected throughout the air basins and regions within the air basins to establish the number of test lanes required for statewide implementation. Figure 4-20 indicates the usage of the model. The inputs to the simulation model are variable to allow testing of different combinations of configurations, resources, and procedures to determine maximum throughput.

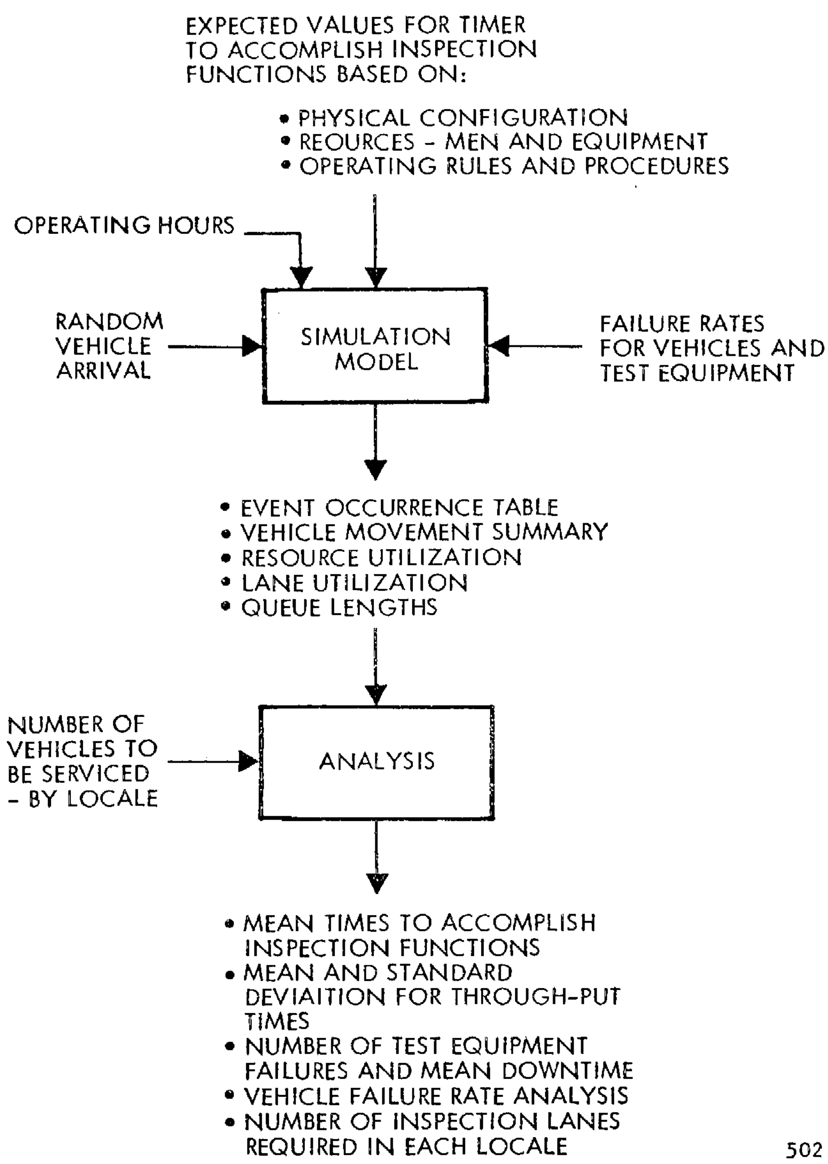

Figure 4-20. USE OF THE SIMULATION MODEL